

Profiling the meat quality of blue wildebeest (*Connochaetes taurinus*)

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DECLARATION

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GENERAL ABSTRACT

The aim of this study was to provide baseline data on the overall yield and quality (physical attributes, chemical composition, sensory profile and optimum aging period) of six muscles [*Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST), *Infraspinatus* (IS) and *Supraspinatus* (SS)] of blue wildebeest bulls (*Connochaetes taurinus*) culled from an extensive and semi-extensive production system in South Africa. There is a need for this information due to the lack of scientific information on the meat quality of this species and the effects of various extrinsic and intrinsic factors thereupon.

In the first trial, eight blue wildebeest bulls were culled from a semi-extensive production system and eight from an extensive system where ages were matched and divided into adult and sub-adult treatments. Semi-extensive wildebeest showed to have the potential to increase carcass yield by having significantly higher undressed carcass weights (208.2 ± 11.14 kg), carcass weights (112.1 ± 6.38 kg) and dressing percentages (53.8%) than the extensive (168.8 ± 14.59 kg, 84.9 ± 7.55 kg and 50.2%, respectively). Semi-extensively raised blue wildebeest also showed higher weights for external and internal offal parts as well as producing significantly ($p < .0001$) higher total muscle yields (19.8 ± 0.91 kg) than the extensive system (14.8 ± 1.22 kg), with differences being associated with the loin and hindquarter muscles and not the forequarter muscles.

Differences in the physical meat quality attributes of blue wildebeest muscles were influenced to a greater extent by muscle type than production system or age. Production system had an influence on muscle drip loss; higher values being associated with the semi-extensive system. Age influenced the drip loss, cooking loss, tenderness and lightness of the muscles; the sub-adult meat samples exhibiting the more desirable physical characteristics. Ultimate pH (pH_U), drip loss, cooking loss, tenderness and colour were influenced ($p \leq 0.05$) by muscle type. The mean pH_U values ranged from 5.6 - 5.8, with the forequarter muscles (IS and SS) having a higher pH_U ($p \leq 0.05$) compared to the other muscles. The drip loss values for the SM muscle ($1.9 \pm 0.22\%$) were significantly ($p < .0001$) higher when compared to the other muscle types. The lowest drip loss values was associated with the IS muscle ($1.0 \pm 0.07\%$). Similarly the lowest cooking loss was also associated with IS muscle and the highest for the ST and SM muscles. For tenderness, the highest Warner Bratzler shear force values were observed for the SM muscle (43.6 ± 1.44 N) and the lowest for the forequarter muscles (IS = 24.1 ± 1.16 N and SS = 24.4 ± 1.07 N). All muscles in this study delivered the meat colour associated with game with L^* value < 40 , high a^* and low b^* values.

Production system influenced the moisture, protein and ash content but not the intramuscular fat (IMF) content of the final meat product. Meat from the semi-extensive system had a higher ($p \leq 0.05$) protein and ash content, while the extensive system had a higher moisture content ($p \leq 0.05$). A significant difference in all the proximate chemical components was observed between the six muscle types. The proximate composition ranging from 75.9 - 78.5% moisture, 19.3 - 22.3% protein, 1.6 - 2.1% IMF and 0.99 - 1.1% ash content. The forequarter muscles were associated with

the highest moisture and IMF and lowest protein content. Although production system and muscle type significantly influenced the proximate composition of blue wildebeest meat, the differences were numerically small and therefore it is debatable whether these differences are of biological value and relevance to human nutrition.

With the production systems differing in nutritional management, variations in dietary composition and exercise can influence the fatty acid content and consequently the sensory quality of the meat produced. The sensory profile was determined by descriptive sensory analysis (DSA) in addition to various physical measurements (pH, thaw loss, cooking loss and Warner Bratzler shear force) and fatty acid profile to establish the sensory quality of blue wildebeest meat. The main effects had minor influences on the sensory profile with the meat being classified with an intense gamey, beef-like and sweet aroma and flavour. The former being attributed to be due to high concentration of polyunsaturated fatty acids (PUFA). The meat was associated with low tenderness (high shear force) with a relatively moderate initial juiciness and sustained juiciness attributed despite a very low intramuscular fat content of the meat. Differences in fatty acid profiles were attributed more to differences in production systems (differences in diets and activity) than age or anatomical location of muscles. Stearic acid (C18:0), linoleic acid (C18:2n6c) and α -linolenic acid contributed the highest percentage to the total fatty acids, with the meat measuring a PUFA:SFA ratio and n6:n3 (omega 6:omega 3) ratio within the recommended guidelines.

With the knowledge that variation in meat quality has been found in animals of the same age and species. An additional eight blue wildebeest bulls (aged 28 months) were obtained from a semi-extensive production system that had a mean undressed carcass weight of 234.1 ± 5.55 kg, a mean carcass weight of 125.4 ± 3.18 kg and a dress out percentage of $53.6 \pm 0.56\%$. The physical meat quality parameters were influenced by muscle type, with the exception of the ultimate pH. The forequarter muscles were found to be desirable with regards to drip loss, cooking loss, Warner Bratzler shear force and intense bright red colour in comparison to the hindquarter muscles. For the chemical analyses it was found that the hindquarter muscles had a lower moisture content, higher protein content and lower intramuscular fat (IMF) content than the forequarter muscles. The optimum aging period for vacuum-packed blue wildebeest LTL and BF muscles was also determined. The muscles were portioned and aged for 2, 5, 9, 14, 20 and 28 days at 4°C. This study found that to achieve optimum tenderness vacuum packed blue wildebeest LTL muscles should be aged for nine days and BF muscles for fourteen days at 4°C.

ALGEMENE UITTREKSEL

Die doel van die studie was om data te verskaf oor die algehele opbrengs en kwaliteit (fisiese eienskappe, chemiese samestelling, sensoriese profiel en optimale verouderingstydperk) van ses spiere [*Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST), *Infraspinatus* (IS) en *Supraspinatus* (SS)] van blouwildebees bulle (*Connochaetes taurinus*) geproduseer onder ekstensiewe en semi-ekstensiewe produksiestelsels in Suid-Afrika. Daar is 'n behoefte aan die inligting weens die gebrek aan wetenskaplike inligting oor die vleisgehalte van hierdie spesie en die gevolge van verskeie ekstrasie en intrinsieke faktore daarop.

In die eerste proef is agt blouwildebees bulle van 'n semi-ekstensiewe produksiestelsel en agt van 'n ekstensiewe produksiestelsel geoes, waar ouderdomme aangepas en verdeel is in volwasse en subvolwasse behandelings. Semi-ekstensiewe blouwildebeeste het getoon dat hulle die potensiaal het om karkasopbrengs te verhoog deurdat hulle beduidende hoër intakte karkas gewigte (208.2 ± 11.14 kg), karkasgewigte (112.1 ± 6.38 kg) en 'n uitslagpersentasie (53.8%) as die ekstensiewe blouwildebeeste (168.8 ± 14.59 kg, 84.9 ± 7.55 kg en 50.2%, onderskeidelik) gehad het. Semi-ekstensiewe blouwildebeeste het ook hoër gewigte vir eksterne en interne afvaldele gehad, asook beduidende ($p < .0001$) hoër totale spieropbrengste (19.8 ± 0.91 kg) in vergelyking met ekstensiewe diere (14.8 ± 1.22 kg), waar verskille met die lende en agterkwartspiere geassosieer was en nie met die voorkwartspiere nie.

Verskille in die fisiese vleiskwaliteitskenmerke van blouwildebees spiere is meer deur spiertype as produksiestelsel of ouderdom beïnvloed. Produksiestelsel het 'n invloed op die drupverlies van die spier gehad, waar hoër waardes met die semi-ekstensiewe stelsel geassosieer is. Ouderdom het die drupverlies, kookverlies, sagtheid en ligtheid van die spiere beïnvloed; die subvolwasse vleismonsters het meer wenslike fisiese eienskappe getoon. Finale pH (pH_U), drupverlies, kookverlies, sagtheid en kleur van die vleis is deur spiertype beïnvloed ($p \leq 0.05$). Die gemiddelde pH_U waardes het gewissel van 5.6 - 5.8, met die voorkwartspiere (IS en SS) wat 'n hoër ($p \leq 0.05$) pH_U waarde, in vergelyking met die ander spiere, gehad het. Die drupverlies waardes vir die SM spier ($1.9 \pm 0.22\%$) was beduidend ($p < .0001$) hoër as dié van die ander spiertipes. Die laagste drupverlies waardes is geassosieer met die IS spier ($1.0 \pm 0.07\%$). Soortgelyk het die IS spier ook die laagste kookverlies gehad waar die ST en SM spiere weer die hoogste kookverlies gehad het. Vir sagtheid is die hoogste Warner Bratzler skeurkrag waardes vir die SM spier (43.6 ± 1.44 N) en die laagste vir die voorkwartspiere (IS = 24.1 ± 1.16 N en SS = 24.4 ± 1.07 N) waargeneem. Al die spiere het 'n vleiskleur gehad wat tipies met wildsvleis geassosieer word (d.i. L^* waardes < 40 , hoë a^* waardes en lae b^* waardes).

Produksiestelsel het die vog-, proteïen-, en asinhoud beïnvloed, maar nie die intramuskulêre vetinhoud (IMF) van die finale vleisproduk nie. Vleis van die semi-ekstensiewe stelsel het 'n hoër ($p \leq 0.05$) proteïen- en asinhoud gehad, terwyl vleis van die ekstensiewe stelsel 'n hoër voginhoud (p

< 0.05) gehad het. 'n Beduidende verskil is waargeneem vir al die proksimale chemiese komponente tussen die ses spiertipes. Die proksimale samestelling het gewissel van 75.9 - 78.5% vog-, 19.3 - 22.3% proteïen-, 1.6 - 2.1% IMF- en 0.99 - 1.1% asinhoud. Die voorkwartspiere word met die hoogste voginhoud en IMF-inhoud en die laagste proteïënhoud geassosieer. Alhoewel produksiestelsel en spiertype die proksimale samestelling van blouwildebeesvleis beduidend beïnvloed het, was die verskille numeries klein en daarom is dit debatteerbaar of hierdie verskille biologiese waarde of relevansie vir menslike voeding het.

Met die produksiestelsels wat verskil in voedingsbestuur, kan variasies in diëtsamestelling en oefening die vetsuurinhoud en gevolglik die sensoriese kwaliteit van die vleis wat geproduseer word, beïnvloed. Die sensoriese profiel is met beskrywende sensoriese analise (*descriptive sensory analysis*, DSA) bepaal, bykomend tot verskeie fisiese metings (pH, ontdooiverlies, kookverlies en Warner Bratzler skeurkrag) en vetsuur profilering om die sensoriese gehalte van blouwildebees vleis te bepaal. Die hoof effekte het klein invloed op die sensoriese profiel gehad, met die vleis wat met 'n intense wild, beesagtige en soet aroma en geur geklassifiseer is. Eersgenoemde word toegeskryf aan 'n hoë konsentrasie poli-onversadigde vetsure (*polyunsaturated fatty acids*, PUFA). Die vleis was geassosieer met 'n lae sagtheid (hoë skeurkrag) met 'n relatiewe gematigde aanvanklike sappigheid en volgehoue sappigheid toegeskryf ondanks die vleis se lae IMF-inhoud. Verskille in vetsuur profile is meer toegeskryf aan verskille in produksiestelsels (d.i. verskille in diëte en aktiwiteit) as die verskille in ouderdom of anatomiese ligging van spiere. Steariensuur (C18:0), linoleïensuur (C18:2n6c) en α -linoleïensuur het die hoogste persentasie tot die totale vetsuur samestelling bygedra. Die vleis het ook PUFA:SFA (*polyunsaturated fatty acids:saturated fatty acids*) en n6:n3 (omega 6:omega 3) vetsuur verhoudings binne die aanbevole riglyne bevat.

Met die wete dat variasie in vleiskwaliteit gevind is in diere van dieselfde ouderdom en spesies, is agt bykomende blouwildebees bulle (28 maande oud) met 'n gemiddelde intakte karkasgewig van 234.1 ± 5.55 kg, 'n gemiddelde karkasgewig van 125.4 ± 3.18 kg en 'n uitslagpersentasie van $53.6 \pm 0.56\%$, verkry uit 'n semi-ekstensiewe produksiestelsel. Die fisiese vleiskwaliteit parameters is beïnvloed deur spiertype, met die uitsondering van die pH_U. Die voorkwartspiere was wenslik met betrekking tot drupverlies, kookverlies, Warner Bratzler skeurkrag en intense helder rooi kleur in vergelyking met die agterkwartspiere. Volgens die chemiese analyses, het die agterkwartspiere 'n laer voginhoud, hoër proteïënhoud en laer IMF-inhoud as die voorkwartspiere gehad. Die optimale verouderingstydperk vir vakuum verpakte blouwildebees LTL en BF spiere is ook vasgestel. Die spiere is in porsies verdeel en verouder vir 2, 5, 9, 14, 20 en 28 dae by 4°C. Daar is bevind dat optimale sagtheid bereik word wanneer die vakuum verpakte blouwildebees LTL spiere vir nege dae en BF spiere vir veertien dae by 4°C verouder word.

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LIST OF ABBREVIATIONS

ABBREVIATION	EXPANSION
°C	Degree Celsius
3n	Omega-3 polyunsaturated fatty acid
6n	Omega-6 polyunsaturated fatty acid
%	Percentage
GLM	General Linear Models
ANOVA	Analysis of Variance
BF	<i>Biceps femoris</i> muscle
cm	Centimetre
DFD	Dark, firm and dry meat
FA	Fatty acid
FAME	Fatty acid methyl esters
g	Gram
ha	Hectare
IMF	Intramuscular fat
IS	<i>Infraspinatus</i> muscle
kg	Kilogram
LSMeans	Least Squares means
LTL	<i>Longissimus thoracis et lumborum</i> muscle
m	Metre
mg	Milligram
MHC	Myosin heavy chain
min	Minute
ml	Millilitre
ml/min.	Millilitre per minute
mm	Millimetre
mm/s	Millimetre per second
MUFA	Monounsaturated fatty acids
N	Newton
<i>n</i>	Number
<i>ns</i>	Non-significant
<i>ng</i>	Not detected
PUFA:SFA	Polyunsaturated to saturated fatty acid ratio
pH _u	Ultimate pH

ABBREVIATION	EXPANSION
PUFA	Polyunsaturated fatty acid
s	Seconds
SFA	Saturated fatty acids
SM	<i>Semimembranosus</i> muscle
SS	<i>Supraspinatus</i> muscle
ST	<i>Semitendinosus</i> muscle
t	Tons
v/v	Volume to volume ratio
WHC	Water-holding capacity
WBSF	Warner Bratzler shear force
μl	Microliter
μm	Micrometre

GLOSSARY OF TERMS

TERM	DEFINITION
Adult animal	An animal that has reached sexual maturity and has the ability to reproduce.
Aging	A process by which meat is held under controlled temperatures for a period of time. This allows enzymatic activity to degrade complex proteins causing changes in flavour and tenderness.
Ante-mortem	Before death.
Behavioural manipulation/Breeding programs	An example of manipulation is to remove all breeding aged males besides a selected individual with advantageous characteristics to breed with the aim to influence the offspring produced.
Breeding camp	A fenced-in enclosure which allows behavioural manipulation of a wild species to control which animals are to breed.
Brewers grain	Solid residue left after the processing of germinated and dried cereal grains (malt) for the production of beer and other malt products. The main grain used for brewing is barley, but wheat, maize, rice sorghum and millet can also be used. Brewers grain are fed to ruminants as they are palatable and readily consumed when in good condition. It is rich in protein (27-33% DM), relatively rich in rumen undegradable (by-pass) protein, and fibre (ADF 17-26%) and therefore is suitable when feeding ruminants concentrate-rich diets.
Bulls	Adult uncastrated male of various large animals.
Carcass weight	The mass of an animal after it has been partially butchered and the following parts removed: external offal (head, skin and legs below the knee joint and in case of males, genitals) and internal offal (heart, lungs, kidneys, liver, spleen and gastrointestinal tract consisting of the stomach and intestines).
Caudal	The anatomical term used to describe the posterior location (away from the head) of a muscle.
Colour variant	A wild animal expressing a colour phenotype. They are not a separate species, subspecies or hybrids but are a naturally occurring phenomena that are thought to be as a result of a combination of alleles carrying the genotype for the the expression of the rare colour, usually on recessive allele, found to occur in wild populations and have been made more common by deliberate breeding.
Consumptive utilisation of game species	When game animals are killed as a food source (personal use or for commercial sales), for sport (trophy hunting), for recreation or for population management. Products produced include meat, hides, skins, ivory and live sales.
Conventional livestock farming	This is a term used to describe farming that uses well known traditional methods and techniques.
Cotton oil cake	This is formed when oil is extracted from cotton seeds. It is commonly used as a source of protein for ruminants.
Cranial	The anatomical term used to describe the anterior location (towards the head) of a muscle.

TERM	DEFINITION
Culling	The shooting of selected animals on the basis of age, gender/sex or other characteristics.
Dressing percentage	The percentage of the live animal weight which is the carcass. It is determined by dividing the hot-carcass-weight by the live animal weight.
Eviscerated	To remove one or all organs from the inside of the carcass.
Exsanguinated	The action or process of draining or losing of blood from the animal.
Extensive game ranching/farming	Farming done with little or no interference with the wildlife species in their natural habitat with no effort to domesticate them. Animal populations are expected to survive with little to no food supplementation (with the exception in times of severe droughts) or veterinary care. Also sometimes referred to as wildlife farming, but for consistency in this thesis, the term extensive game farming will be used as this is commonly used in South Africa. Meat production and production of trophies via hunting is the main goal of this type of farming.
Game animals	A term referring to any non-domesticated animals hunted for meat or sport, generally including mammals and birds. However in this thesis it is confined to only ungulate mammal species.
Game farming	Implementation of livestock farming principles to farm with game species while adapting the techniques to fit the natural limitations of individual game species.
Game meat	Often also referred to as African Wildlife meat, is meat that is obtained from game animals.
Harvesting	The indiscriminate shooting of an animal as they are encountered.
Herbivore	Any plant eating animal. They are divided into two groups, medium to large mammal species and small species. In this thesis, herbivores refer to the medium to large mammals that include all antelope species.
Intensive game farming	Wild animal species confined in small to medium size camps or enclosures where they are fenced in to be protected from predators and are provided with most or all their food, water and veterinary requirements.
Lime	A source of calcium used in animal feeding.
Lucerne	Also known as alfalfa. High quality hay that is rich in protein.
Maize	This grain is palatable and suitable for all livestock. It is the most valuable energy source among cereals. It has a high starch content (about 65%), about 4% oil and low fibre content (10% NDF). This grain is low in calcium and supplementation is required.
Molasses	A viscous, dark and sugar-rich by-product of sugar extraction from sugarcane. It is a major feed ingredient used as an energy source (60-70% DM) and a binder in compound feeds. It also improves roughage palatability to increase intake. Cane molasses is also high in sodium, potassium and magnesium, and contains significant quantities of copper, zinc, iron and manganese. However, it is poor in phosphorus (less than 0.1% DM) and supplementation may be required.
Non-consumptive utilisation	Wildlife utilisation that does not include taking off of wildlife. It entails any non-hunting or non-extractive use such as eco-tourism where animals are watched, studied and recorded.

TERM	DEFINITION
Offal	The internal organs and entrails of a butchered animal. Does not include muscle and bone.
Post-mortem	After death
Recreational hunting	The hunting of non-domesticated animals using a rifle or bow with the purpose of obtaining meat. The meat is either processed into biltong or sausage, mostly being consumed by the hunter and his family or friends. The meat may also be sold to local butcheries.
Rigor-mortis	Stiffness at death. The formation of permanent bonds between actin and myosin after the depletion of ATP in muscles
Roasting	A method of cooking where heat is transmitted to the meat by convection, either by normal or forced air, in a closed, preheated oven. The meat is placed on a rack either in or over a shallow pan to catch drippings. The oven door is closed and the meat is not turned during cooking.
Semi-extensive game farming	Animals are supported by regular management interventions to maintain habitat integrity and supplement food and water is provided especially in dry periods at the end of winter. Constant interference through veterinary intervention is not the norm.
Sexual maturity	The age at which the animal has physiologically sexually developed to be able to mate with a female. Fertility has been reached.
Soya oil cake	This high-protein cake is formed when oil is extracted from soyabean (erect leguminous plant).
Strategic supplementary feeding	The feeding of forage to animals to supply nutrients to supplement the needs at that specific time period such as growth, pregnancy, lactation, flushing for fertility etc. (e.g. strategic additional mineral, energy and protein sources) that the natural pasture is deficient in, therefore mostly done when animals are kept in camps. Often practised as production feeding to supply sufficient food for breeding adult stock or for younger animals to meet growth targets.
Sub-adult animal	The period from sexual maturity up to the average age at which members of the species generally reaches social maturity. Social maturity is the age at which the animal has developed sufficient body strength to defeat opposition of its own sex. The animal can now insure that its own genes would be transferred in reproducing to future generations. The animal are now able to maintain a leading functional role within the social hierarchy of the population.
Trophy hunting	The selective hunting of non-domesticated animals (mainly mammals), picked based on specific traits such as large horns, tusks or body size. This type of hunting is done by paying clients in the presence of a professional hunter. The primary products obtained (skins, horns, tusks) are retained by the clients to display as mounted trophies. The meat is generally taken as a secondary product and used locally.
Ungulate	A hoofed mammal, including all antelopes
Venison	Term used to describe meat that is obtained from cervids such as deer that are farmed or obtained from the wild. Under farming conditions the animals may receive special treatment in the form of castration, vaccination against certain diseases and food supplementation.

TERM	DEFINITION
Wheat	Is primarily an energy source due to its high starch content (about 70%DM). Richer in protein than barley and maize. Fibre content is very low (crude fibre less than 3%). Chemical composition of wheat can vary depending on species, cultivars, rowing location, climate and soil fertility.
Wildlife	An informal terms used to describe non-domesticated animal and plant species. In this thesis this term refers to non-domesticated animals.

NOTES

The language and style used in this thesis is in accordance to the requirements of the journal of *Meat Science*. This thesis represents a compilation of manuscripts where each chapter is an individual entity and therefore some repetition between chapters, especially in the Materials and Methods section, was unavoidable.

Results of this study have been presented at the following conference:

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CHAPTER 1

GENERAL INTRODUCTION

Archaeological evidence suggests that 2.6 million years ago hominins (human immediate ancestors) began supplementing their diets with meat to provide adequate energy and nutrients to support the larger developed human brain (Pobiner, 2013). Thus today meat plays an important role in human diets, supplying essential proteins, vitamins and minerals to improve maternal health and early child development (Bwibo & Neumann, 2003; Hoffman, Mostert, Kidd & Laubscher, 2009). Therefore a diet lacking protein sources can result in detrimental health effects, which is currently the case in Africa where large populations are stricken by malnutrition and famine brought on by the lack of protein rich sources, with one in four people considered undernourished in sub-Saharan Africa (FAO, 2015).

Unfortunately this is not a phenomenon that is limited to Africa alone, as the world as a whole is currently facing one of the largest threats to food security and sustainable use of resources. This is as a result of the drastic increase in population numbers (estimated to surpass 9 billion by 2050), while livestock production has largely stagnated or is declining due to various challenges bringing about concerns about the future of livestock farming (Otieno & Muchapondwa, 2016). These challenges include climate change, land shortages, degradation, water scarcity, carbon emission constraints, high feed prices and environmental and welfare legislation limiting the improving of livestock production (Ingram, Eriksen & Liverman, 2010; Cawthorn & Hoffman, 2014; DAFF, 2016; Otieno & Muchapondwa, 2016). These joint effects are projected to therefore cause food yields to fall 25% short of the anticipated demands that need to be met in 2050 to avoid food insecurity (Nellemann *et al.*, 2009). Thus there is currently a pursuit to avoid this crisis by focusing on new or non-traditional animals in supplying high quality protein for human consumption (Cooper, 1995).

Agriculturally, South Africa has made its mark worldwide by presently having one of the fastest growing agriculture industries mainly due to the success of game and scarce game breeding (Taylor, 2016). This industry has grown significantly since the first game auction in 1965 with a 2016 estimate of 10 000 wildlife properties operated by approximately 3500 farmers, covering about 20 million ha of land (Taylor, Lindsey & Davies-Mostert, 2016). This means that about one third of the country's land is currently being utilised for game or game related purposes (Bothma & Van Rooyen, 2005). Therefore game farming is today recognised and organised as a commercial enterprise in the agriculture sector of South Africa, with a 40 fold increase in wildlife since 1960 being found on privately owned wildlife ranches, of which 6 million are estimated to be large herbivores (Taylor, 2016).

This significant shift from conventional livestock farming to game farming, is largely as a result of game farming proving to be more economically viable (generating higher net farm revenues) than livestock farming in the dry regions of sub-Saharan Africa (Berry, 1986; Otieno &

Muchapondwa, 2016). This is mainly because game farming is being driven by diverse income opportunities namely, legal trade, recreational and professional hunting, eco-tourism and meat production (Bothma & Van Rooyen, 2005). Therefore game farming has been defined as the farming of high-valued animals, driven by multiple commodities and requiring low animal stocking rates while reducing land degradation and maintaining biodiversity (Hoffman & Cawthorn, 2012).

Another reason for the success of this agriculture industry and high production turnover is attributed to game animals being able to utilise natural vegetation more efficiently than livestock due to physiological and behavioural mechanisms optimized through centuries of adaptation making them exceptionally well adapted to sparse vegetation, harsh terrains and extreme climatic conditions (Muir, 1989; Cole, 1990). Therefore game animals can strategically and sustainably utilize the inhospitable scrub into food and energy.

Game animals have been shown to prosper when farmed using systems similar to that used for cattle while adjusting the principles to the limitations of individual game species. This has resulted in the development/adaptation of various combinations of production systems to optimise animal production. Most commonly found are extensive and semi-extensive production systems. In an extensive system animals are left to roam freely with little or no additional inputs relative to the size of the land, thus relying on natural vegetation with limited human intervention primarily restricted to times of drought. While semi-extensive farming involves keeping the animals in camps large enough to allow free movement but regular management intervention is practiced to optimize production and health. These interventions are commonly subjected to strategic supplementary feeding, breeding programs and water provision (Oberem & Oberem, 2016). Thus a semi-extensive production systems provides animals with optimum nutrition all year round with little or no predation and disease stress. Therefore the level of activity and forage consumed by game species differs between the production systems and thus their development and growth. This all causes changes in both the intrinsic and extrinsic aspects of the carcass and meat quality (Hoffman, Kroucamp & Manley, 2007)

With the significant growth of the game farming industry there is great potential for the development and growth of the game meat industry. Not only does game meat have the potential to supplement the red meat production that will contribute positively to food security but also effectively utilises the marginal grazing lands and reduces environmental degradation as well meeting consumer demands ascribed to the health, price and welfare concerns associated with red meat consumption (Godfray *et al.*, 2010). However the success of the game meat industry will only become possible if emphasis is placed on increased research and development of products aimed at increasing productivity with consistent quality and safety, with sufficient marketing strategies and better communication of quality and nutritive properties of the meat (Cawthorn & Hoffman, 2014). This is because consumer uptake of game meat has frequently been hindered by poor quality perceptions and inadequate information on nutritional quality (Hoffman, Muller, Schutte, Calitz & Crafford, 2005). South Africa has a rich variety of game species that are unique in dietary regimes

being classified as either grazers, browsers or mixed feeders which all contributes to differences in quality and nutrient composition of the meat and therefore species specific research is required (Bothma, Van Rooyen & Du Toit, 2010).

One ungulate species in South Africa that has received little attention as a meat producer is the blue wildebeest (*Connochaetes taurinus*), which has become a popular addition to all forms of game farms with numbers increasing rapidly on privately owned farms. This is because blue wildebeest are known to be hardy, highly adaptable, fertile and resistant to most tropical diseases (Furstenburg, 2002). They are also one of the most preferred hunting species among the biltong and trophy hunters (Van der Merwe, Scholtz & Saayman, 2011). Often the primary aim of farming these animals are to produce high quality animals for live-sale, trophy hunting or used in the breeding of golden wildebeest (Gnu). Golden wildebeest is a naturally occurring colour variant and not a sub-species of the blue wildebeest, thus farmers make use of behaviour characteristics to breed animals of selected traits. In order to produce animals of perfect health and optimum condition, good management practises are essential. This often includes the regular culling of surplus or sub-standard stock, mainly bulls, especially in golden wildebeest breeding programs as to allow bulls of a specific colour to become dominant, thus blue wildebeest bulls as well as the hybrids (also known as splits) between golden bulls and blue cows are suitable for meat production (Bezuidenhout, 2012). Currently however there is limited data available on the meat quality of blue wildebeest, with no data available on the influence of different production systems in which this species is currently being raised.

Therefore the primary aim of this study was to establish whether production system, age and muscle type has an influence on carcass characteristics, physical meat quality, chemical composition, nutritional value, sensory profile and the optimum ageing period of meat from blue wildebeest bulls culled in South Africa. This will provide baseline data that will allow the game meat industry to take cognisance on whether the above mentioned factors should be taken into account when culling this game species for meat production. Additionally, the results will influence the marketing of meat products obtained from this species making it available to consumers, aimed at bringing about consumer loyalty.

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CHAPTER 2

LITERATURE REVIEW

ABSTRACT

To determine the profile of a subject is to present its history and a detailed description or analysis thereof. Without the growth and development of the game industry in South Africa the meat industry would have maintained its focus only on producing meat products derived from domestic species, therefore the history and development of this industry plays an important role in the identification of game meat and its potential. The initial part of this review therefore focuses on the history and description of the game industry. Once a meat product is obtained its overall quality regarding its appearance, nutrition, safety and sensory quality is what is important for consumer acceptance and in order to compete with existing products. It is known that meat quality, which includes sensory, physical and chemical properties, nutritional composition and consumer acceptability are influenced by both the intrinsic nature of the species and the production conditions (extrinsic factors) to which the animals are subjected to. With the use of literature the effect of these factors that are related to this study were reviewed and defined. With species having a significant influence on meat quality, the animal under study, blue wildebeest (*Connochaetes taurinus*), is also introduced and described to conclude the review.

Keywords: Game industry, Meat quality, Blue wildebeest

2.1. THE SOUTH AFRICAN GAME INDUSTRY

2.1.1. History

Before 1960, farmers in Africa believed that livestock and wild animals could not co-exist in an area because of competition for grazing and the transmission of diseases (Joubert, 1977). In order to avoid this, uncontrolled slaughtering and the removal of wild animals became a common practice, developing into somewhat of a sport to allow domestic livestock, cattle (*Bos taurus*), sheep (*Ovis aries*) and goats (*Capra hircus*) to prosper (Carruthers, 2008). Unfortunately this over-exploitation resulted in a significant decrease in the population numbers of game species on privately owned farms as well as the extinction of large bodied game species such as the quagga (*Equus quagga*) and blue buck (*Hippotragus leucophaeus*) (Pollock & Litt, 1969; Adams, 2004).

In the 1960s, Agricultural and Game Departments started to change with regards to this objective after studies conducted by Dasmann & Mossman, (1961) on a farm in Zimbabwe (then known as Rhodesia), showed that game animals could survive and prosper together with cattle and that their utilisation had enormous potential to help support protein hungry Africa. These findings soon brought about a combination of scientific and attitudinal changes towards how people valued and respected wild animals, encouraging ideas about conservation, management and sustainable development as well as identifying their importance in the economy and ecology of Africa (Pollock & Litt, 1969; Carruthers, 2008).

With South Africa being a country with large amounts of arid and semi-arid regions where resources cannot be utilised efficiently by even the toughest of cattle breeds, where rainfall is low and marginal for livestock production, farmers began converting livestock production to wildlife use in search of a more economically viable option (Bothma & Van Rooyen, 2005; DAFF, 2010). Wild antelopes have become adapted to the harsh environmental conditions associated with the various African habitats over long periods of time, developing, physiologically, the ability to utilise natural vegetation more efficiently than cattle, which were only introduced to Southern Africa in the fourteenth century (Bigalke, 1966). Thus a larger number of game animals can stock a specific area of land compared to cattle as they have lower nutritional requirements (Pollock & Litt, 1969; Von La Chevallerie & Van Zyl, 1971; Cole, 1990). Other advantages that game species have over cattle include: low-quality cattle take longer to reach maturity (with antelopes reaching commercial weight requirements in half the time); higher percentage of meat in relation to total body weight, less water dependent, can be farmed in tsetse-infested areas, can withstand a wide range of temperatures from low to high and are generally more disease resistant (Pollock & Litt, 1969; Von La Chevallerie & Van Zyl, 1971; Cole, 1990).

Besides game species thriving in areas previously unsuitable for conventional livestock farming, there are several other socio-political, economic and ecological factors that have contributed to the change from livestock to integrated game farming. The increased need for protein to support

the growing African population encouraged the search for an alternative protein source to that of traditional livestock. Political influence caused a collapse and change in the agricultural regime, removing subsidies to farmers, control boards and other state organisations that protected farmers. This resulted in farmers no longer being able to rely on financial aid from the government causing great economic losses as services now had to be sourced from private companies (Van Der Merwe, Saayman & Krugell, 2004). With the change in laws also came opportunities for land claims and change in property rights that caused uncertainty about the future of farmers in South Africa (Carruthers, 2008). In addition farmers are continuously overwhelmed with the increase in livestock theft, increased labour costs, cost of disease control and effect of climate change, all of which are encouraging the conversion of commercial livestock farms to game farms (Carruthers, 2008; Otieno & Muchapondwa, 2016).

With an annual conversion rate of 2.0-2.5%, about 300 000 ha per year, a change in South African law facilitated game farming into an industry, with private ownership of wildlife being granted in 1991 (Van der Merwe *et al.*, 2004). Since then the industry experienced an annual growth rate of 5.6% up to the mid-2000s after which the increase in intensive breeding practises accelerated the growth to 6.75% per year. This resulted in the wildlife industry becoming the fastest growing agricultural sector of South Africa. Currently there is an estimated 10 000 game ranches and more than 4 000 mixed game and livestock farms registered with an additional 6 000 unregistered farms and reserves in South Africa. These areas cover about 25% of the country's total land area, compared to the 6.0% that is declared as conservation areas (Taylor, Lindsey & Davies-Mostert, 2016). Therefore there is more game than forty years ago and population sizes continue to increase with no threats of extinction, which was the case until the 1960's. The only difference is that the animals are not free for the taking but occur on privately or state owned land where they are linked to a monetary value (Carruthers, 2008).

2.1.2. The industry defined

The game industry has grown positively in the last decade, with a rapid expansion in the size and development of several sectors within the industry, attributed to extensive research that has focused on increasing the knowledge and optimisation of game farming. With several studies highlighting how the manipulation of natural population dynamics by managing individual species needs, controlling age and sex structures and selecting the best performing game species annually, can increase the performance of a population up to 20% (Furstenburg, 2002).

There are two main forms of game utilisation on privately owned farms, game farming and game ranching. Game farming is defined as a farming system where one or a few animal species are semi-domesticated on small areas of land and integrated with other farming practises. This type of farming has been practised in South Africa for decades. For example there is evidence through ancient paintings, how Bushman sustainably farmed eland (*Taurotragus oryx*) for trade rather than

hunting them (Pollock & Litt, 1969). On the other hand, game ranching requires scientific management of many species in their natural habitat on a large area of land with no intention of domestication and is often practised for conservation purposes. The two forms differ in the efficiency of land use, capital, labour and management (Barnes, 1998).

The game industry is supported by four main economic pillars that are individually economically proficient and contribute to the national income, livelihoods and national development of South Africa. They can be broadly classified into consumptive and non-consumptive uses and are breeding and live game sales, hunting, ecotourism and processed products (Fig. 2.1). Many game farms operate to profit from more than one of these production sectors. They often practise game farming and game viewing together successfully, profiting from both the game and tourist industry while contributing to nature conservation, thus game farming is both ecologically and financially sustainable (Pollock & Litt, 1969). Bigalke (1966) summarized the potential of game farming by stating 'the utilisation of game farming may well be a means of increasing productivity without damage to the environment. It may indeed lead not only to the conservation but also improvement of soil and vegetation in some areas.'

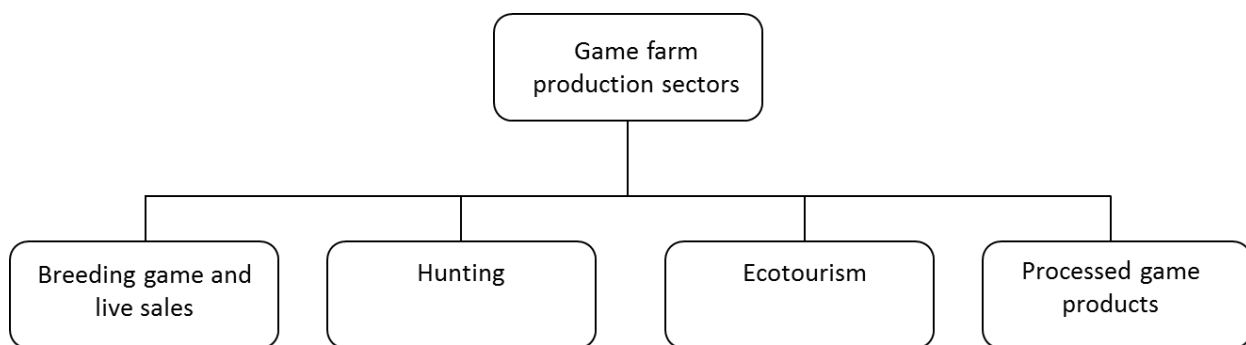


Figure 2.1 The four main production segments of the game industry.

Game species are therefore either utilised consumptively, non-consumptively or both. The consumptive utilisation is when animals are harvested or culled as a food source, for personal use or for commercial sales; for sport such as trophy hunting, for recreation and/or for population management. Products produced from consumptive utilisation includes meat, hides, skins, ivory or live sales (Barnes, 1998).

In the 19th century the devastating consequence of over hunting was recognised by some hunters, who then set out to protect the remaining game populations (Adams, 2004). Soon unique and endangered animals were being subjected to breeding programs, similar to that of cattle, in intensive and semi-extensive environments to increase population numbers in the most efficient way. With the success of the breeding programs, the animals became associated with high monetary values, encouraging more farmers to invest into this type of farming. Breeding of game can be divided into two categories. Firstly the breeding of common species such as springbok (*Antidorcas marsupialis*), impala (*Aepyceros melampus*), kudu (*Tragelaphus strepsiceros*) etc. Secondly is the

breeding of endangered or rare species such as buffalo (*Syncerus caffer*), sable (*Hippotragus niger*), roan (*Hippotragus equinus*), golden wildebeest (*Connochaetes gnou*) and rhino (*Ceratotherium simum* and *Diceros bicornis*). In both these categories emphasis is often placed on producing the animals to be sold at auctions to fellow game breeders (Van Der Merwe *et al.*, 2004). However, because of the large number of game breeders currently operating in the industry, the market is becoming saturated resulting in stagnating, and even decreasing, prices with the total revenue generated in 2016 declining by 10% from the previous years (Fig. 2.2a). This was accompanied by 16% less animals being sold at South African auctions that same year (Fig. 2.2b). The largest decline was seen in the selling of plains game (34%), whilst the selling of rare game animals increased by 46% (African Wildlife Auction, 2016). Regardless of this decline, the live sales still generated a total revenue of R4.328 billion, of which private sales contributed an estimated R2.453 billion (Taylor *et al.*, 2016).

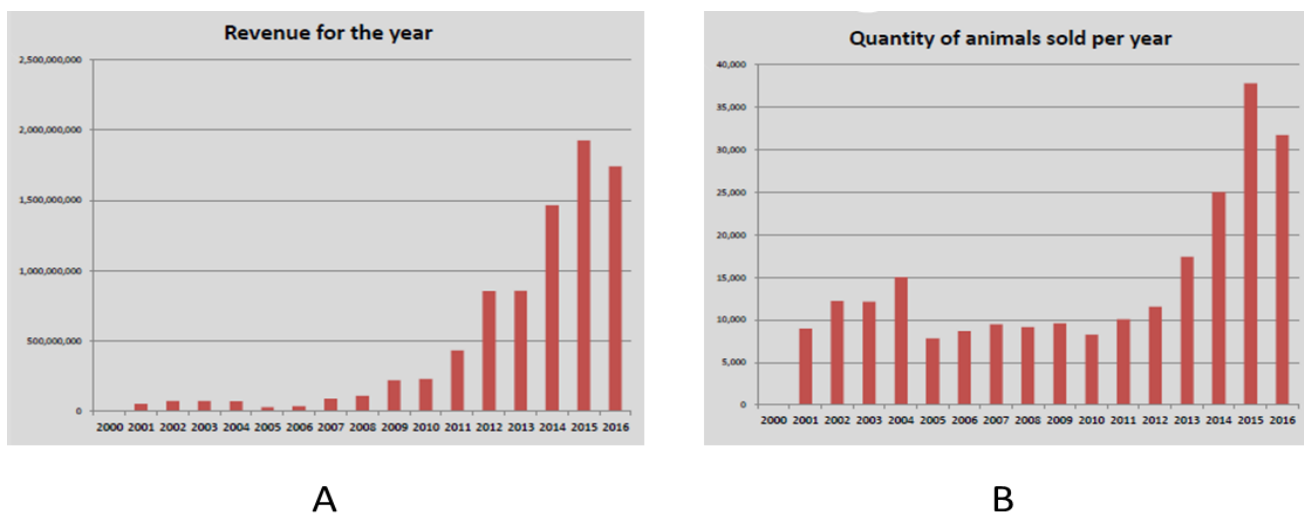


Figure 2.2 A) The total revenue generate from live sales from 2000 to 2016 in SA Rands; **B)** The total quantity of animals sold at live sales every year since 2000 to 2016 (African Wildlife Auction, 2016).

The hunting industry can be divided into two categories: trophy hunting and biltong hunting. It has been estimated that this form of consumptive use has generated R2 billion in 2016. In the 20th century wealthy Europeans and Americans started venturing to Africa to take part in trophy hunting (Adams, 2004). Trophy hunting is a means of selective hunting where tourists pay to hunt, in the presence of a professional hunter, individual (non-domestic) animals with exceptional physical traits such as large horn lengths, large body sizes or unique coat colours (Barnes & De Jager, 1996; Taylor *et al.*, 2016). Today trophy hunting is a major industry that plays an important role in the conservation of many game species as the high prices paid for hunting have facilitated the recovery of many endangered species such as bontebok (*Damaliscus pygargus*), black wildebeest (*Connochaetes gnou*) and cape mountain zebra (*Equus zebra*) (Flack, 2003). There are several other positive factors

associated with trophy hunting such as generating revenues in areas where ecotourism may not be viable, high revenues are generated from low volumes of hunters, it acts as a tool for population control and also helps prevent illegal hunting by assisting in anti-poaching initiatives (Barnes & De Jager, 1996). In 2014 trophy hunting generated a total revenue of approximately R1.96 billion (Taylor *et al.*, 2016).

Biltong hunting has been practised by local people for centuries, where non-domesticated animals are hunted with a bow or rifle to obtain meat for consumption (Taylor *et al.*, 2016). The meat is either processed into biltong (dried and cured meat) or other meat products such as sausage, steaks, etc. (Jones, Arnaud, Gouws & Hoffman, 2017). The total revenue generated by biltong hunting was R0.651 billion in 2014 (Taylor *et al.*, 2016).

As the game industry continues to grow it is important that new markets and industries be developed to avoid a sudden collapse and safeguard the industry in the future (Furstenburg, 2002). Thus more attention should be given to the commercialisation of game meat due to the availability of animal resources (Kohn, Kritzing, Hoffman & Myburgh, 2005).

The value of game meat production in South Africa was first recognised in the 1950's and was mainly focused on exports to Europe (Carruthers, 2008). South Africa initially exported about 2 million tons of game meat per year which mainly included springbok, kudu and zebra. However, in the 1990's game meat was associated with the spread of foot-and-mouth disease which made consumers aware of the safety and quality related to meat products, causing a decrease in game meat consumption during this period (Hoffman, Muller, Schutte, Calitz & Crafford 2005). Regardless of this, South Africa exported 160 000 deboned game meat carcasses in 2005 (Hoffman & Wiklund, 2006). However these diseases weren't managed and maintained within disease zones, leading to a ban being placed on the export of game meat in 2011. In February 2014 the ban was lifted but game meat production and consumption still contributes only a small amount to the formal international and local meat market (Taylor *et al.*, 2016). Game meat has the potential, as a valuable protein source in a continent that is lacking the adequate supply of meat, to assist in supporting the increasing population.

South Africans consumes approximately 2.9 million tons of meat per year, however only 2.4 million tons are locally produced (Torry, 2015). This calculation does not include meat from game animals. Therefore in order to meet the demands of consumers, 0.5 million tons of meat is required to be imported. There could be thus be food security and foreign exchange concerns. With sufficient game meat locally available more focus should be placed on the utilisation to counteract the concerns surrounding meat imports. Taylor *et al.* (2016) reported that game farms in South Africa produced 23 700 tons of game meat from a combination of trophy hunting and culling during 2014, with 15 700 tons of meat obtained from biltong hunting. McCrindle, Siegmund-Schultze, Heeb, Zárate & Ramrajh, (2013) suggested that if all game meat resources including offal were used sustainably, thousands of tons of meat could be produced annually, meeting the requirements of the

domestic consumer market. A medium game animal such as eland, kudu, blue wildebeest etc. at slaughter produces meat that is equivalent to one bovine unit or six sheep (Taylor *et al.*, 2016).

For the consumptive utilisation of game, trophy hunting has the highest net return per average animal followed by biltong and recreational hunting, live sales and then meat production (Berry, 1986). However, it is difficult to calculate a value for live sales as individual animals/species can fetch extremely high prices; e.g. a buffalo bull 'Horison' is considered the most expensive buffalo in the country after it was valued at over R176 million per quarter share at an auction in February 2016. However, when an index based on animal numbers was developed the weighted net values showed that meat production was the most profitable of all the production sectors and trophy hunting was the lowest, giving the lowest return per unit area. This can be seen in the revenues generated in 2014 through consumptive utilisation where the industry generated R2.6 billion from hunting, R4.3 billion from live sales and R610 million from game meat, Figure 2.3 (Taylor, 2016). Therefore live sales is often done in addition to hunting practises by farmers to increase the income potential. However, due to the increased knowledge on the breeding of game animals, breeders have become more discerning in the animals they select to breed with and therefore there is a high animal production turnover. As a result farmers have to focus on alternative utilisation methods to utilise surplus or sub-standard stock while maintaining a constant increased profitability. Here game meat production is the best option in maintaining the financial viability of game farms (Berry, 1986).

Non-consumption utilisation of game includes any non-hunting or non-extractive use such as eco-tourism where animals are watched, studied and recorded. Eco-tourism has been defined by Taylor *et al.* (2016) as the 'responsible travel to natural areas that conserves the environment and improves the well-being of local people'; South Africa's scenic beauty and wildlife remain a major attraction to both local and international tourists. It is estimated that tourist arrivals are to increase from 6 million in 2000 to 30.5 million in 2020 (WTO, 2001). This influx of tourists has resulted in eco-tourism representing R1 billion in direct revenue with about 700 private game reserves focusing mainly on tourists in South Africa (Taylor *et al.*, 2016).

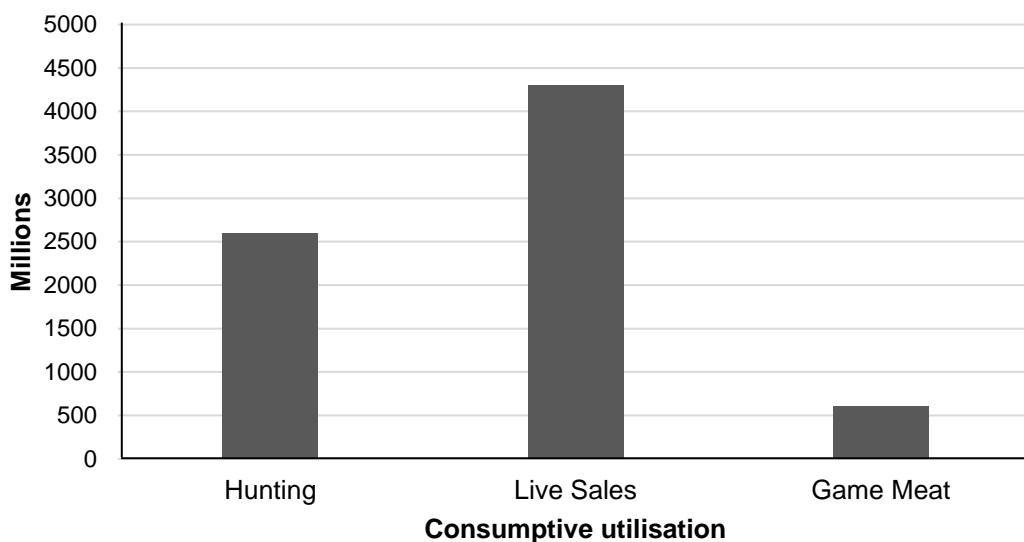


Figure 2.3 Revenues generated in 2014 through consumptive utilisation (Taylor, 2016).

2.2. MEAT QUALITY

Meat quality traditionally referred to the properties important for the sustainability of the meat for eating, processing and storage such as retail display (Andersen, Oksbjerg, Young & Therkildsen, 2005). Thus the main attributes of interest are: safety, nutritional value, flavour, texture, water-holding capacity, colour, lipid content, lipid composition, oxidative stability and uniformity (Andersen *et al.*, 2005). Due to the drastic changes with regards to animal production that are continuously occurring nationally and internationally, the conditions under which animals are produced such as management system, genotype, feeding, pre-slaughter handling, slaughter method, chilling and storage is now also all considered a multivariate property of meat quality (Andersen *et al.*, 2005). This is due to the fact that parameters that influence meat quality ranges from carcass characteristics such as the amount of marbling, the texture of muscles fibres, the firmness and the colour of the meat and fat as well as the character of the bones. While meat quality is also linked to the quality of retail and cooked cuts defined by colour, aroma, flavour, juiciness and tenderness (Marchello & Dryden, 1968). These parameters are affected by characteristics within an animal as well as between animals of the same breed, sex and environment. Therefore in order to control and maintain consistent quality (regarding its appearance, nutrition, safety and sensory quality) it is important to understand the influence of intrinsic (genetics) and extrinsic (environment) factors on muscle composition and biochemical processes that cause variation in meat quality (Klont, Brocks & Eikelenboom, 1998).

2.2.1. INTRINSIC FACTORS AFFECTING RUMINANT MEAT QUALITY

2.2.1.1. Species

Species is a genetic aspect and therefore influences variables such as muscularity, lifespan and gestation period. In addition to this, every species also has its own behavioural and survival techniques that affect the growth and development of the animal. The body composition varies between different species due to differences in forage consumed and their dependence on water (Ledger, 1963). Most species have a cumulative growth pattern that varies with severe changes in food availability most often caused by changes in season where a lack of growth and weight increase is associated with winter grazing and the opposite seen with summer grazing due to the nutritional status of the plants. This causes differences in carcass characteristics such as mass, yields and conformation as well affecting the composition of the muscle as it changes in shape with growth and therefore, quality post-mortem (Warriss, 2000). These differences include physical and chemical quality parameters (Ramírez-Retamal & Morales, 2014).

Physical quality parameters refer to important aspects of meat that are measured using physical testing methods. These methods quantitatively determine aspects of meat such as acidity (pH), water holding capacity (WHC), surface colour and tenderness. With analytical methods being used to quantify the chemical composition of the meat generally in the form of moisture, protein, fat and inorganic constituents in the selected portions of meat.

The ultimate pH (pH_U) is determined by the lactic acid concentration that is produced from glycogen during anaerobic glycolysis measured 24 hours post-mortem (Lawrie & Ledward, 2006). Hoffman *et al.*, (2011) found differences in the pH of *Longissimus thoracis et lumborum* (LTL) muscles (described in section 2.2.1.3.1) when comparing between different species. Impala had the highest pH_U (5.76) while blue wildebeest had the lowest pH_U (5.41). This difference is often attributed to how susceptible the different species are to ante-mortem stress during harvesting which consequently influences the amount of glycogen in the muscle at slaughter. This further influences post-mortem enzyme activity and therefore differences in pH_U and the aging rate, influencing the aging period required to reach optimum tenderness post-mortem (Dransfield, 1994; Wiklund, Stevenson-Barry, Duncan & Littlejohn, 2001).

Water-holding capacity of meat differs between species, age and muscle function due to differentiation within the muscles. It has been found that the water-holding capacity of pork is lower than that of beef (Den Hertog-Meischke, Van Laack & Smulders, 1997). The initial juiciness is the impression of wetness that is perceived after the first few chews which is due to a rapid release of fluid from the meat. Initial juiciness depends on the WHC of the meat and the quantity of intramuscular fat present in the meat (Hoffman, Mostert & Laubscher, 2009). Therefore meat with a low WHC capacity (often linked to high ultimate pH) will have a decreased perceived juiciness (Honikel, 1998).

Colour of the meat also differs between species due to differences in myoglobin content of the muscle. This is because the colour of the meat is influenced by the chemical status and quantity of the myoglobin in the meat (Lawrie & Ledward, 2006; Neethling, Suman, Sigge & Hoffman, 2016; Neethling, Suman, Sigge, Hoffman & Hunt, 2017). As example, freshly cut pork of the LTL forms oxymyoglobin (Figure 2.3) at a faster rate than seen in cattle LTL (Lawrie & Ledward, 2006). This is because different muscles have different inherent respiratory activity varying under given conditions.

Tenderness is heritable, making species one of the major factors affecting meat tenderness, as this characteristic is influenced by variation in muscle metabolism that differs between species (Swatland, 1994a; Lawrie & Ledward, 2006). This causes differences in the coarseness of the muscle fibre bundles and thus tenderness. The size of the animal which differs between species is related to the muscle grain size, for example cattle are larger in size than sheep causing greater coarseness in their muscles (Lawrie & Ledward, 2006). This infers that coarse grains lead to less palatable stringy meat (Purslow, 2005). However even though studies continuously highlight that small diameters of muscle fibres is related to tender meat, this single variable is of extremely limited value in predicting the toughness of meat due to the multifactorial nature of texture (Purslow, 2005).

When using a Warner-Bratzler attachment a mean shear force measured in Newton (N) of 78.5 N or lower is considered acceptable by the New Zealand beef and lamb quality standards, but most meat products should measure 117.7 N (Slater, 2009). Determining tenderness through sensory analysis is defined by the impression of tenderness in the first five chews, where a zero score indicates extremely tough and a score of 100 equals extremely tender. Together with the collagen content and type, level of muscle contraction post-mortem, the fat content of the carcass is most commonly another explanation for meat either being classified as tender or tough (Neethling, Hoffman & Muller, 2016). The amount and percentage of fat content differs between species as well as between ages, sexes and the nutritional status of the animal at slaughter (Hocquette *et al.*, 2010).

Sustained juiciness is the impression formed after two or three chews using the molar teeth. Fat has an influence in stimulating saliva production in the mouth, therefore fatter animals are expected to have a higher sustained juiciness as has been seen in sheep (Hoffman *et al.*, 2009). The average fat content of most game species is very low compare to domestic livestock (Hoffman & Wiklund, 2006). However, Hoffman *et al.* (2009) found no differences between kudu and impala animals with higher fat content and those with less amounts of fat. This could be that game species have very low concentration of intramuscular fat; too little to make a significant contribution to the sustained juiciness of the meat.

Intramuscular fat of game species has been shown to be less than 3%, with the exception of blesbok (*Damaliscus pygargus phillipsi*) whole carcasses that were found to be 4.6% (Van Zyl & Ferreira, 2004). The latter authors found when comparing the physical composition of whole springbok, blesbok and impala carcasses (they ground up the whole carcass), that impala had a higher percentage of protein than either springbok or blesbok. Irrespective of species, males had

lower fat content compared to females. The dressing percentages were also determined with blesbok having a dressing percentage of 49.5 - 50.8%, springbok 56.2 - 57.6% and impala 54.7 - 58.2%. When the carcass weights, dressing percentages and proportional distribution of tissues in these three species were determined; they had a high production of total usable products with an average of 84.8% versus 76.7% found in sheep and cattle. Comparing the chemical composition of the three species to sheep, the game species had a higher protein, moisture and ash (salt and inorganic constituents such as minerals) percentage with a much lower fat content (Van Zyl & Ferreira, 2004).

Hoffman, Smit & Muller (2008) found that in blesbok the main fatty acids were palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1) and linoleic acid (C18:2n-6c). This was similar for kudu and impala species. However, the concentration of the various fatty acids differed. For the impala, the highest quantity was for stearic acid, followed by palmitic acid, linoleic acid and the lowest quality of the four fatty acids was oleic acid. Similar results were found in springbok meat (Hoffman *et al.*, 2007). However quantities were not similar for kudu, where the highest concentration was oleic acid followed by linoleic acid, stearic acid and palmitic acid (Hoffman, Mostert, & Laubscher, 2009). These differences are attributed to differences in diet (Hoffman, Kritzing, & Ferreira, 2005); as example, blesbok are highly specialised grazers whilst kudu are browsers (Neethling, 2016).

For human health the consumption of omega-3 (n3) fatty acids are very important with a recommended maximum ratio of 4 for omega-6 (n6)/omega-3 (n3) (WHO, 2003).

. For kudu and impala this ratio was found to be below the maximum with impala having a higher ratio (3.76) than kudu (2.22) (Hoffman, Mostert, & Laubscher, 2009). For springbok and blesbok it has been found to be substantially lower, with a ratio of 1.98 and 1.57, respectively (Du Buisson, 2006). All these ratios indicating that game meat can be classified as being healthy (WHO, 2003). When considering the nutritional value of meat the polyunsaturated/saturated fatty acid (PUFA/SFA) ratio is also of great importance, where the recommended PUFA:SFA ratio is >0.7 (WHO, 2003). This has been recorded for a number of game species such as buffalo (0.97), blesbok (0.93), black wildebeest (1.01) and springbok (0.76) (Hoffman & Wiklund, 2006).

Hoffman *et al.* (2009) studied the comparison of kudu and impala LTL muscles on the sensory attributes of cooked samples. A difference in flavour between the two species was reported, with impala having a more intense game flavour. This gamey flavour has been defined as a flavour of a wild animal that is associated with a combination of liver-like and metallic flavours (Neethling *et al.*, 2016). This flavour difference can be explained by the difference in the PUFA/SFA ratio, as lipids have been found to release specific flavours during heating. These differences are attributed to diet (Neethling, Muller, van der Rijst, & Hoffman, 2017).

2.2.1.2. Age at slaughter

The age at slaughter has significant influences on the quality of meat as age is linked to the developed of the body; thus animals of different ages will differ in carcass maturity in terms of body

weight and muscle development. Tenderness is a meat quality characteristics that has been shown to be influenced by the age of an animal at the time of slaughter (Purslow, 2005). Variation in the tenderness of muscles from animals of the same species of differing age has been shown to be due to the differences in the rate of myofibrillar protein degradation and the increase in muscle fibre bundle size with age (Koochmaraie, 1994). Older animals have repeatedly been shown to be less tender (higher shear force values) than younger animals, indicating that tenderness decreases with age, possibly influenced by collagen becoming less soluble (cross-linkages forming soluble heat-resistant structures) with age, causing meat to become less tender (Hoffman *et al.*, 2009).

The composition of muscles also change with an increase in animal age as with age carcasses get heavier and the proportion of fat increases while the proportion of muscle and bone decreases (Warriss, 2000). In pork, age does not seem to influence the water-holding capacity (the ability of the meat to retain water), but in beef age seems to play a role, with calves having a higher water-holding capacity. The differences could be explained by differences in pH within and between muscles and differences in the type of protein present in animals of different ages (Lawrie & Ledward, 2006).

Daszkiewicz *et al.*, (2015) found that with increasing age of farmed fallow deer (*Dama dama*), the intramuscular fat content also increased. Similarly a study on the chemical composition of springbok of different ages found that age had a significant effect on the moisture and intramuscular fat content of the LTL muscle; lambs had a higher mean moisture content than sub-adults and adult springbok (Hoffman *et al.*, 2007). Also, Hoffman *et al.* (2007) reported that the meat became darker with increasing age; the sub-adult animals had a higher L* (lightness) value than the adult springbok.

A change in fatty acid composition has also been shown to be influenced by animal age where an decrease in myristic acid (C14:0) and palmitic acid (C16:0) has been noted after weaning while stearic acid (C18:0) and oleic acid (C18:1) increased regardless of the energy value of the diet of black wildebeest (Van Schalkwyk, 2004). Zembayashi & Nishimura (1996) investigated the fatty acid composition of bulls (cattle) compared to steers and found that bulls had a higher percentage of polyunsaturated fatty acids (PUFA) of the total fatty acids compared to steers. This finding was attributed to the differences in the phospholipid/triacylglycerol ratio associated with differences in carcass fatness (Hood & Allen, 1971).

2.2.1.3. Skeletal muscle properties

Skeletal muscles of vertebrates are muscles that attach to bones and facilitate voluntary skeleton movements by performing a series of contractions (Swatland, 1994b). Each muscle is made up of thousands of muscle fibres that run along its length, being characterised by morphological traits and contractile and metabolic properties (Lee, Joo, & Ryu, 2010). These muscle fibres are arranged in bundles, consisting of many contractile units called myofibrils, held together by connective tissue

(Swatland, 1994b). Muscle fibres make up about 75-90% of the muscle volume and therefore the number of fibres and the size of the fibres are an important factor in determining muscle mass (Rehfeldt, Fiedler, Dietl, & Ender, 2000). Skeletal muscles exhibit a wide variety of shapes, sizes anatomical locations and physiological functions (Listrat *et al.*, 2016). These different muscles are characterised by their composite appearance containing muscle fibres, connective tissue and intramuscular fat which all play a role in determining meat quality.

Muscle fibres are formed under genetic control during foetal development by cellular differentiation from mesodermal cells that form a series of transitional cell types (Swatland, 1994b). Following cellular differentiation, transitional cells undergo physiological differentiation forming one of three different types of muscle fibres that vary within themselves (Klont *et al.*, 1998). Type I (slow twitch oxidative), Type IIA (fast twitch oxidative) or Type IIB (very fast twitch glycolytic) (Kohn *et al.*, 2005). These fibre types are differentiated according to their metabolisms and expressed myosin heavy chain (MHC) isoforms that have been identified by observing their physiological responses to histochemical techniques (Cassens & Cooper, 1971; Swatland, 1994b; Kohn *et al.*, 2005).

Type I are small red dark fibres, due to high myoglobin content, that are designed for oxidative metabolism, being rich in oxidative enzymes, low in glycolytic enzymes and low in ATPase activity (Cassens & Cooper, 1971; Kelly & Robertson, 2008; Lee *et al.*, 2010). Research has shown that fibre diameter has an inverse relationship between the oxidative capacity of the fibre, therefore Type I is the smallest, Type IIA intermediate in size and Type IIB is the largest in diameter (Klont *et al.*, 1998). Type I fibres exhibit a slow-twitch which causes a contraction over a longer period of time, being suited for activities requiring strength and endurance that is slow but steady e.g. maintaining posture, breathing, chewing, slow locomotion or long distance running (Swatland, 1994b; Kelly & Robertson, 2008). This type of fibre receives its energy source for contraction by producing ATP via aerobic metabolism that uses blood-borne oxygen for complete oxidation of substrates from fat and glycogen, therefore they are better supplied with capillaries within the muscles in order to maintain a constant oxygen and nutrient supply (Swatland, 1994b; Kohn *et al.*, 2005). Type I has more capillaries per fibre than type II fibres and therefore an increased resistant to fatigue as well as no, or minimal, accumulation of lactic acid (Kelly & Robertson, 2008). This fibre population contains large amounts of mitochondria, low glycogen content and high lipid content (intramuscular fat). The latter contributes to the sensory qualities such as taste, juiciness, flavour and tenderness of the final meat product (Hocquette *et al.*, 2010).

Type II fibres obtain their energy in the form of ATP through a faster glycolytic process. Since glycogen stores are more rapidly depleted than oxygen supplies, these fibre types are associated with activities that require rapid alternating effort rather than continuous activity (Kelly & Robertson, 2008). Therefore Type II fibres are also more prone to anatomical changes due to changes in energy demands than that of Type I fibres. For example, they are small in muscles that don't carry out strenuous exercise and increase in size once introduced to repeated physical

demands required for fast and strenuous work for a short period of time. Thus they contract quickly but fatigue quickly as well. These fibres are associated with a fast twitch and low lipid content. Type II fibres are subdivided into two types, IIA and IIB.

Type IIA fibres are also red due to high myoglobin content but unlike Type I this fibre population is fast twitching that fatigue slowly. These fibres are able to produce ATP from both oxidative and glycolytic pathways via fast aerobic metabolism due to the admixture of glycolytic and oxidative enzymes, causing it to enter rigor-mortis faster than Type I without the accumulation of lactic acid (Kohn *et al.*, 2005). Type IIB fibres are white due to low myoglobin content and are designed for glycolytic metabolism (anaerobic), being rich in glycolytic enzymes and strong ATPase activity (Cassens & Cooper, 1971; Kelly & Robertson, 2008; Lee *et al.*, 2010). They have the largest diameter of all fibre types, with the fastest rate of contraction and therefore most susceptible to fatigue and lactic acid accumulation by glycolysis (Kelly & Robertson, 2008). Based on the different fibre types constituting the muscle, skeletal muscles are classified into two types, red muscle (red meat or slow muscle) and white muscle (white meat or fast muscle) (Swatland, 1994b).

The distribution of these fibre types differ within muscles depending on the function of the muscle. Armstrong, Delp, Goljan & Laughlin (1987) found that in pigs the deepest muscles of the limbs have the highest percentage of low oxidative Type I fibres, while the superficial muscles have the highest percentage fast glycolytic Type IIB fibres. Similar in cattle *semitendinosus* (ST) muscles the glycolytic activities decrease and the oxidative capacity increase towards the distal end of the muscle (Brandstetter, Picard, & Geay, 1997). The same study also found that with increasing age the regular intra-muscular pattern of the muscle fibres diminished and became longitudinally homogeneous in all the fibre characteristics studied. This could be due to physiological changes or chronological delays caused by organic, physiological or environmental factors. Therefore it is noted that animals with high muscularity have high glycolytic activity (high concentration of Type II fibres) and reduced development of intramuscular fat (IMF) (Hocquette *et al.*, 2010).

The fibre types of an animal differentiate clearly just before or after birth (Cassens & Cooper, 1971). Therefore at birth the quantity of muscle fibres is fixed and will only increase in size (length and thickness) during growth. Thus the change in the muscle fibre is dependent on the degree of exercise and the plane of nutrition to which the animal is exposed (Cassens & Cooper, 1971). Kohn, Hoffman & Myburgh, (2007) studied the skeletal muscle fibre types in four Southern African wild ruminants (kudu, blesbok, blue and black wildebeest) and found that the fibre type can change as a result of external stimuli such as physical activity and environmental factors. For example it was found that the kudu which has the ability to jump over a 2 m high fence with ease will have higher portions of type II fibres to assist in this. Differences were also found between the animals depending on their terrain, with the kudu inhabiting hilly areas whereas the blesbok, blue wildebeest and black wildebeest prefer flat terrains. Therefore kudu had low type I and high type II fibres. The blesbok is considered the most active of these species and therefore had a higher level of type IIA fibres. Body

mass was also found to have an influence on the fibre type expressed, with a linear increase in type II found with an increase in body mass regardless of the activity pattern of the animals. Therefore there are several factors that can cause a change in the muscle fibre type and metabolism thus causing a change in physical-chemical compositions that will influence the meat quality attributes of each muscle.

The colour of the meat is influenced by the chemical status and quantity of the myoglobin in the meat (Figure 2.4) (Lawrie & Ledward, 2006; Neethling *et al.*, 2016; Neethling *et al.*, 2017). Higher concentrations of deoxymyoglobin molecules are found in freshly cut meat, forming a reddish, purple colour. This pigment is very important as it is the colour desired by consumers (Lawrie & Ledward, 2006). Once the meat is exposed to oxygen, deoxymyoglobin is transformed into oxymyoglobin due to the denaturing of the globin molecule, giving off a desired bright red colour (Węglarz, 2010). Therefore during experiments, samples are left to bloom for at least 30 min to allow for the oxygenation of the meat (Honikel, 1998). However, the colour changes to a brown undesirable colour if the meat is exposed to oxygen for prolonged periods of time, due to the transformation of oxymyoglobin to metmyoglobin (Węglarz, 2010). The quantity of myoglobin is associated with muscular activity and high level of activity is related to more myoglobin in the muscle (Lawrie & Ledward, 2006). Therefore the quantity of myoglobin differs between species, breeds, sex, age, type of muscle and training. Bulls are therefore expected to have more than cows and steers more than calves etc. which was confirmed by Hoffman, Kritzing & Ferreira (2005) in impala. It was found that male impala had higher myoglobin contents (7499.99 mg/kg muscle) than the females (7345.18 mg/kg muscle) from the same region. The presence of IMF and collagen within a muscle causes variation in colour and can influence colour measurements (Honikel, 1998; Neethling *et al.*, 2017).

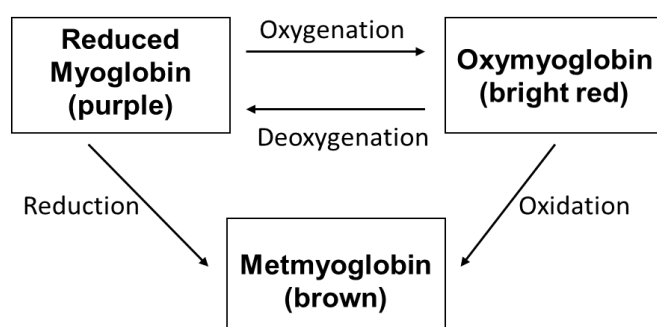


Figure 2.4 Flow chart indicating how the chemical status of myoglobin influences meat colour.

2.2.1.3.1. *Muscle type and anatomical location*

The muscle structure of most of South African game species are similar to that of bovines, with a few variations present for selective species (Hoffman & Bigalke, 1999). In order to serve individual consumers meat gets sold in relatively small packages in markets, placing emphasis on meat quality as variations in quality are now more easily observed. In order to make quality control more feasible,

specific muscles or groups of muscles are removed as individual muscles differ in biochemical composition and therefore eating quality (Lawrie & Ledward, 2006). Different muscles also differ in tenderness, juiciness, flavour and overall palatability that are brought on by losses in cooking and thawing (Jeremiah, Gibson, Aalhus, & Dugan, 2003).

Muscles from the forelimb, hind limb and back are mostly used for commercial meat production. Therefore in this study the following muscles were studied: *supraspinatus* (SS) and *infraspinatus* (IS), *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM) and *longissimus thoracis et lumborum* (LTL) (Figure 2.5). These muscles differ in function and activity levels within a carcass and between game species and therefore will differ in composition and possibly meat quality. This is due to differences in fibre type composition with regards to the total number of fibres (TNF), cross-sectional area of the muscle fibre (CSAF) and the length of the fibre. This all depends on anatomical location, age, weight, breed and muscle growth (Cassens & Cooper, 1971).

The *M. supraspinatus* (SS) and *M. infraspinatus* (IS) are two muscles located in the shoulder/forelimb of an animal (Table 2.4). The *M. supraspinatus* (SS) is located dorsal to the spine or the ridge on the scapula where it extends the shoulder joint and helps in preventing shoulder dislocation by assisting in the extension of the shoulder. The *M. infraspinatus* (IS) is found ventral to the scapular spine, acting as a ligament that aids in flexing, moving and stabilising the shoulder (Swatland, 1994c). These shoulder muscles are found to be intermediate with regards to toughness and require complete cooking in order to make them tender (Swatland, 1994c). The SS muscle is classified as a 'red muscle' due to its high oxidative fibre content, low protein content and high connective tissue concentration (Lawrie & Ledward, 2006). Both these muscles are small and have a well-developed and tough epimysium, which if cooked, contributes to the toughness of these two muscles.

Hind limb muscles are relatively large in size producing large volumes of moderately tender meat making them among the finest muscle cuts (Swatland, 1994c). The *M. biceps femoris* (BF) is the largest muscle in the hind limb with fairly uniform tenderness (Table 2.4). It is located on the lateral face where it extends the hip, stifle and hock joints when lifting the hind foot off the ground (Swatland, 1994c). On the posterior face of the hind limb is the *M. semitendinosus* (ST) and *M. semimembranosus* (SM) muscles (Table 2.4). These muscles are large in size with the SM muscle on the medial end of the ST muscle. The latter like the BF muscle extends the hip, stifle and hocks when lifting the hind foot but additionally also flexes the stifle joint. The SM muscle also extends the hip and adducts the limb (Swatland, 1994c). In the ST muscle the muscle fibres are not uniform with larger muscle fibres being found in the anterior (top) portion of the muscle, making it a muscle with less desirable texture (Vestergaard *et al.*, 2000). These three muscle make up the main extensor muscles in the hip.

The loin muscles have been found to give rise to the most tender meat of all the skeletal muscles, with a high protein concentration and desirable taste, making this major muscle of the erector spinae commercially the most valuable (Kauffman, Habel, Smulders, Hartman & Bergstrom, 1990). The loin muscle consists of two sections *longissimus thoracis* (LT) and *longissimus lumborum* (LL) collectively known as *M. longissimus thoracis et lumborum* (LTL) (Table 2.4) (Swatland, 1994c). The LT section is at the cranial end and the LL section is at the dorsal end. This muscle maintains the balance and stability of an animal during movement. Stretching along the length of a number of vertebrae it also assists in neck and respiratory movements as well as aiding in the flexing of the vertebral column. Like the ST muscle, the muscle fibres are not uniform along the length of the LTL muscle, with larger fibres found in the posterior (bottom) end of the muscle than the anterior end (top) (Swatland, 1994c). Therefore the tenderness of the muscle decreases from the centre of the muscle towards both ends (Swatland, 1994c).

Texture is the function of the size of the fibre bundles constituting the muscle. Coarse-grained muscles such as the SM muscle have large bundles and fine grained-muscles such as the ST muscle have small bundles (Lawrie & Ledward, 2006).

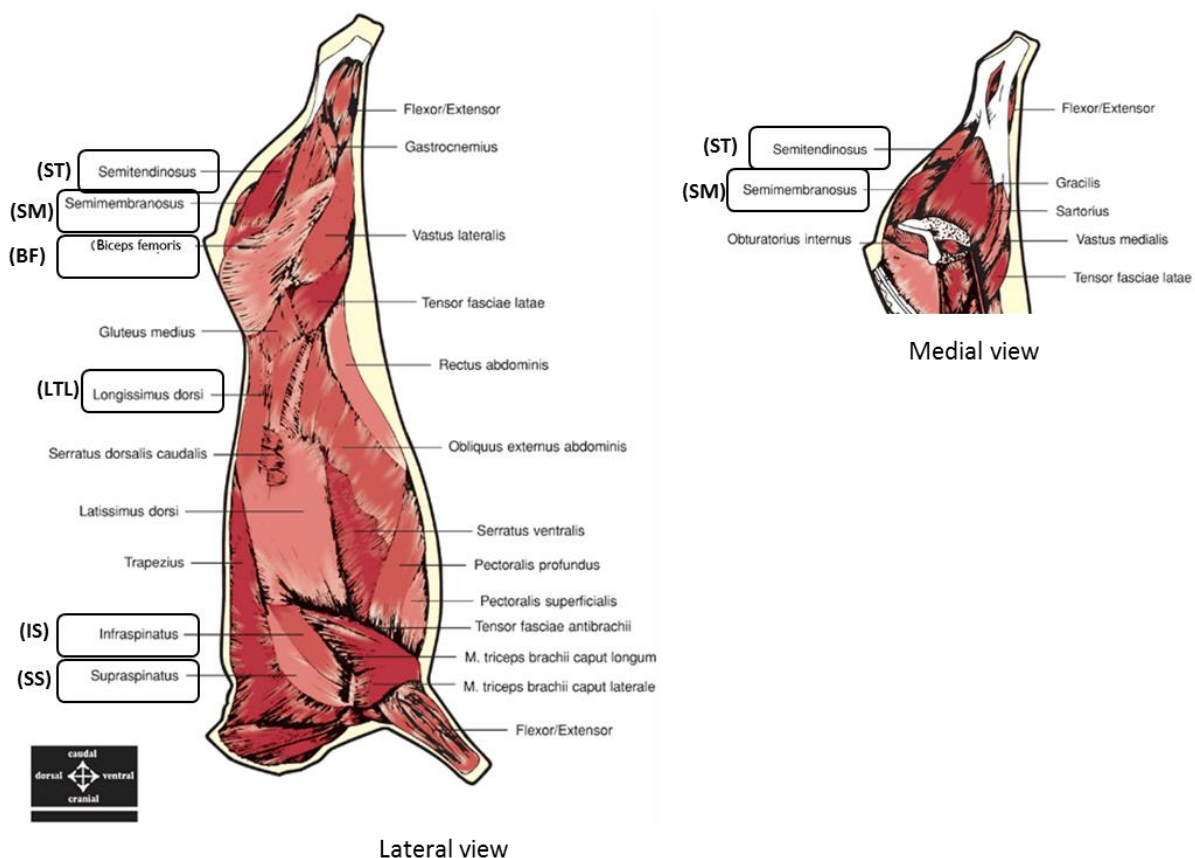


Figure 2.5 The lateral view of the anatomical location of the six muscles removed for analyses in this thesis, with a medial view showing the ST and SM for clarity, adapted from Aus-Meat (2005).

2.2.2. EXTRINSIC FACTORS AFFECTING RUMINANT MEAT QUALITY ANTE-MORTEM

2.2.2.1. Multi-causal factors: Production system

Due to the popularity and success of farming game species there has been a development of various combinations of intensive, semi-extensive and extensive systems to optimise animal production. Intensive farming is where the highest production is achieved on the smallest possible land area making use of strategic supplementary feeding and breeding programs (Taylor *et al.*, 2016). Semi-extensive farming involves keeping the animals in camps/paddocks large enough to allow free movement but regular management intervention is practiced to optimize animal production and health. Similar to intensive farming the animals are subjected to strategic supplementary feeding, breeding programs and water provision (Oberem & Oberem, 2016). Thus intensive and semi-extensive production systems provide animals with optimum nutrition all year round with little or no predation and disease stress. In an extensive system animals are left to roam freely with little or no additional inputs relative to the size of the land with the exception during times of drought. Therefore the level of activity and forage consumed by game species differs between the production systems

and thus their development and growth. This all causes changes in both the intrinsic and extrinsic aspects of the carcass and meat quality (Neethling, 2016).

Extrinsic factors affect weight gain, age at slaughter and carcass weight of the animals, while intrinsic factors affects the meat products by influencing carcass composition and conformation, fat content and colour, meat colour, tenderness and flavour (Webb & Erasmus, 2014). Currently in the more intensive systems animals are mostly produced for live game sales thus ante-mortem factors such as diet, age at slaughter and selection of breeding stock for advantageous traits are manipulated. So as to produce animals of optimum condition and health, essential management strategies such as the removal of surplus and substandard stock to avoid pressure being placed on natural resources, are required. Farmers are therefore actively looking for methods to utilize these animals that will contribute to the increased profitability of the farm as they simply utilize the habitat while filling up roaming space and carrying capacity whilst not contributing to reproduction (Furstenburg, 2002; Bezuidenhout, 2012). This is where the utilisation of these surplus animals for game meat is the best option in maintaining the financial viability of game farms. Since these animals are already subjected to population manipulation through diets etc., it allows for the opportunity to improve meat and sensory quality of game meat products (Hoffman, Mostert, Kidd, & Laubscher, 2009). This is the main reason why farming with deer species under a managed production system similar to that of traditional livestock farming has become so common and successful, particularly in New Zealand. However with wild African ungulate species, domestication is not always ideal and therefore control over the quality of the product is often a problem.

Production system affects the physiology of the muscle with regard to the energy status and fibre concentration contributing to colour, juiciness and tenderness of the meat, as animals are exposed to different feeding regimes and exercise conditions (Olsson & Pickova, 2005). Therefore it can be expected that wild and farmed game species produce meat of different quality and therefore should be marketed as a different products.

2.2.2.1.1. *Effect on the physical meat quality attributes;*

Extensive systems usually produce animals with slower growth rates due to no supplementary feeding (e.g. strategic additional mineral, energy and protein sources) and rely only on natural vegetation that is season dependent and may not always have enough energy in their diets to accumulate glycogen and lipid energy reserves (Webb & Erasmus, 2014). Whereas in an intensive and semi-extensive production systems, game species are subjected to daily supplementary feeding and therefore are always maintained at a high nutrient level. Frylinck, Strydom, Webb & du Toit (2013) established that when steers of the same age but from pasture-fed (extensive) and concentrate-fed systems (comparable to intensive and semi-extensive game systems) were slaughtered, the carcass weights of those raised extensively were lower than the concentrate-fed animals. Wiklund, Andersson, Malmfors & Lundström (1996) slaughtered reindeer (*Rangifer*

tarandus) that had received no supplementary feeding and compared the pH_U and glycogen levels to animals that were fed supplementary feeding for 5 and 2 months prior to slaughter. It was reported that animals that received no supplementary feed had low glycogen muscle levels (100 mmol/kg dry weight) and high pH_U values. The animals fed supplementary feed 2 months prior to slaughter had double the amount of glycogen (200 mmol/kg dry weight) and animals fed for 5 months prior to slaughter had double the amount of glycogen in their muscles than those fed 2 months (400 mmol/kg dry weight). This trend was again shown by Wiklund, Johansson & Malmfors (2003) where reindeer fed commercial feed had lower pH_U (measured in the LTL and BF muscles) compared with reindeer that grazed on natural pasture. Thus pH_U is influenced by both pre-slaughter activity such as the composition of forage consumed as well as whether the animal is subjected to physical muscular activity (exercise) (Swatland, 1994a).

The hunting of game species can often be a strenuous and stressful process as animals raised extensively are not accustomed to handling and therefore pre-slaughter chasing could cause stress brought on by inherent survival instincts. A pH decline that is considered normal is from a physiological pH of 7.0-7.2 in the muscles of live animals to an pH_U of 5.3-5.8 post-mortem (Honikel, 2004). Daszkiewicz *et al.* (2015) reported that the average pH_U of the LTL muscle of farmed fallow deer was higher (5.88) when compared to wild fallow deer that had an average pH of 5.53. In addition the high pH of farmed fallow deer was accompanied by a high water-holding capacity observed through a low drip loss measurement. This is because at a high pH proteins are above their isoelectric point, exhibit a decreasing rate of denaturation and increased binding to water molecules. Where post-mortem glycolysis is slow (slow breakdown of ATP), and the carcass is rapidly cooled before the onset of rigor mortis, water-holding capacity will also be enhanced. However the temperature of the carcass must not be cooled too quickly as this can result in cold-shortening increasing toughness and decreasing water-holding capacity.

The low average pH_U of wild game species was found to be consistent with previous studies on wild roe deer (*Capreolus capreolus* L.) by Daszkiewicz, Kubiak, Winarski & Koba-Kowalczyk (2012), where the average pH_U for female animals were 5.48 and males 5.47. This can be explained by the fact that farmed fallow deer unlike farmed game species in South Africa, are subjected to pre-slaughter handling such as gathering and sorting, compared to wild deer that are simply hunted.

When animals are under-nourished it can cause a high pH_U value in the meat due to insufficient glycogen reserves in the muscles (Priolo *et al.*, 2001). As mentioned, animals raised extensively rely on natural vegetation that, depending on season, could be low in quality affecting the nutrient level of the animal's muscles. However, it has been found that the diet that the animals consume have very little effect on the colour perceived in the meat, but that colour is influenced by carcass fatness, pH_U , animal age, carcass weight and IMF content (Priolo *et al.*, 2001; Neethling *et al.*, 2017). Thus there is a high correlation between pH_U and meat colour.

Meat colour is influenced by the presence of pigments whose concentration is based on tissue composition and fibre structure (Węglarz, 2010). Therefore, meat colour is influenced by forage type and the level of activity performed by the animal. The effect of forage has been reported showing that cattle raised extensively on grass have a darker red meat colour than those fed on concentrates (as in intensive and semi-extensive game farming systems); the meat colour having been identified using both objective (lightness) and subjective (brightness) measurements (Priolo *et al.*, 2001).

Frylinck *et al.* (2013) found that steers raised extensively had lower glycolytic potential resulting in slower pH declines causing a higher incidence of dark-firm-dry (DFD) meat, as well as having higher shear force values and greater variation in tenderness. This is mostly attributed to animals being more active in extensive production systems, resulting in higher myoglobin concentrations found in red oxidative muscle fibres, than domesticated animals (Vestergaard *et al.*, 2000). DFD meat is when meat is characterised by a dark colour (lower CIE L* value on a colour meter) at the surface of the cut muscle, being more dry than normal meat, having a decrease in desirable taste and limited durability due to the development of a gummy structure caused by increased WHC (Honikel, 1998; Węglarz, 2010). This quality of meat is not readily accepted by consumers. Animals fed on concentrated diets as in the intensive and semi-extensive farming systems are less likely to have DFD meat, as it has been shown that animals on concentrated diets have an increased capacity for post-mortem glycolysis, which is a beneficial component in the conversion of muscle to meat, producing 10% brighter meat than meat from animals raised on grass diets (Webb & Erasmus, 2014).

Daszkiewicz *et al.* (2015) observed that farmed fallow deer with high pH_U values was associated with high L* (lightness) values, while meat from wild deer with a lower pH_U had a higher a* (redness) value and b* (yellowness) value. Carcasses with a higher fat percentage cools slower (higher pH decline) and therefore reaches rigor-mortis faster at a higher temperature. This could therefore have an impact on the meat colour, as muscles that have a higher IMF content tend to have a higher WHC, possibly due to the fat loosening up the microstructure allowing more water to be contained (Young, Priolo, Simmons & West, 1999; Priolo *et al.*, 2001). However, Priolo *et al.* (2001) found that carcasses that contained more fat still produced meat of a darker colour.

Muscle fibre characteristics which is influenced by exercise may influence meat quality by affecting the tenderness properties (Vestergaard *et al.*, 2000). Several studies have found that meat from steers farmed extensively had higher shear force values, which is an indicator of tougher meat (Nuernberg *et al.*, 2005; Frylinck *et al.*, 2013; Webb & Erasmus, 2014). Extensively farmed bulls have also been associated with lower sensory scores with regards to tenderness, taste and juiciness when compared to intensive concentrate-fed bulls (Vestergaard *et al.*, 2000). This is possibly explained by the level of activity that is higher in extensively farmed animals thus increasing the muscle fibre concentration, decreasing the IMF, increasing the collagen content in the muscle and

causing a slower protein turnover due to slower growth rates. With regular exercise there is an increase in glycogen levels, being most pronounced in the SM and LD (*Latissimus dorsi*) muscles (predominantly type IIA fibres) and smaller in the ST (predominantly type IIB fibres) muscles of steers (Pethick, Rowe & Tudor, 1995). With an increase in exercise of extensively farmed bulls, the LD and SS muscles had higher concentrations of Type I (slow-oxidative) and Type IA (fast-oxidative), but lower concentrations of Type IIB (fast-glycolytic) fibres when compared to intensively farmed bulls (Vestergaard *et al.*, 2000). Therefore both the fibre type and muscle enzyme activities are considered to be dynamic properties of particularly free-ranging animals (Kohn *et al.*, 2005).

In an intensive system animals are less active and do not migrate in search of food or to avoid predators. It has been reported that animals with a faster growth rate (intensively produced) have more tender meat (Resconi, Campo, Font i Furnols, Montossi & Sañudo, 2010), as they often have lower levels of tenderising enzymes and differences in muscle fibre characteristics (Wiklund, Manley, Littlejohn & Stevenson-Barry, 2003). Therefore the muscle fibre characteristics that influence tenderness can be influenced by differences in feed ration, feed level and physical activity.

There are cases where meat that is produced extensively on natural pasture is ranked lower in tenderness and juiciness than meat produced in semi-extensive systems. This is often related to slower growth rates and less intramuscular fat, as fatness of the carcass affects meat flavours (Olsson & Pickova, 2005). The ultimate pH has also been found to influence the flavour of meat (Webb & Erasmus, 2014); with high-ultimate pH in beef being rated less acceptable than meat with a lower ultimate pH by sensory panellists.

The three sensory properties that are of importance for consumer-purchase include appearance (raw and cooked) and cooked attributes such as texture/tenderness, juiciness, aroma, taste and flavour (Neethling *et al.*, 2016). Game species have characteristic differences when compared to domestic meat species but are evaluated using the same sensory criteria. Game meat is associated with an acquired and unique taste and therefore aroma and flavour have specifically been defined for game species (Neethling *et al.*, 2016). In South Africa game species are exposed to great variations of vegetation's due to difference in seasonal rainfall patterns (Neethling *et al.*, 2016). This results in differences in fatty acid profiles which influences differences in lipid stability during storage and ultimately the sensory qualities of the final product. Therefore the flavour of game meat will differ between different regions as was found in impala and springbok harvested from different regions (Hoffman *et al.*, 2005; Neethling *et al.*, 2017).

Daszkiewicz *et al.* (2015) compared the sensory properties of LTL of wild and farmed fallow deer. It was noted that meat from wild fallow deer received higher scores for aroma desirability, taste desirability and juiciness, while farmed deer meat was perceived to be more tender by the sensory panel. These differences were explained as being due to the different diets the animals consumed and the different ultimate pH values. Wiklund *et al.* (2003) had similar findings while studying the meat of reindeer. It was found that the meat from animals that grazed on natural pasture (similar to

extensive game farming) had a more specific 'wild' and 'gamey' flavour, juiciness and better tenderness than meat from deer that were fed commercial pelleted feed (comparable to intensive and semi-extensive game farming). Thus it is noted that the natural pasture possibly contribute to the 'wild gamey' flavour produced in meat from animals raised on that diet. It was also reported that meat from the commercial fed reindeer scored higher intensities for liver and sweet flavour and lower for off-flavours compared to the meat from natural grazed reindeer (Wiklund *et al.*, 2003). Hoffman *et al.* (2007) reported a significant difference in sensory attributes between springbok meat harvested from different production regions. The different regions affected the rating for game meat aroma, initial juiciness, sustained juiciness and residual tissue.

In the USA, studies on meat flavour have indicated that consumers prefer the flavour intensity associated with animals that have been raised on concentrated grain feed (high in linoleic acid, C18:2), rather than being grass fed (high in α -linolenic acid, C18:3), with the latter being less acceptable (Priolo *et al.*, 2001). However in contrast to this, Keane & Allen (1999) reported that consumers perceived meat from less intensively produced production systems as having a better taste.

2.2.2.1.2. Effect on the chemical composition

Chemical composition of meat can be altered by the production system in which the animals are raised due to the differences in management related to feed composition, feed intake and energy expenditure for maintenance (Olsson & Pickova, 2005). Spontaneous physical activity is less likely to affect chemical composition but rather affects meat quality by influencing the muscle metabolic state at slaughter and pH decline post-mortem that was discussed previously.

Daszkiewicz *et al.* (2015) found that LTL samples collected from wild deer were higher in the total average protein and fat content than that of farmed fallow deer. There were no differences found in the mineral concentrations measured as ash. Various findings have concluded that fat content of meat from fallow deer that are farmed is significantly affected by age and diet, with higher concentrations being associated with older and fed animals (Daszkiewicz *et al.*, 2015). Hoffman *et al.* (2007) found that springbok LTL muscles from different regions differed in chemical composition, possibly due to different nutrients available in their diets. Significant differences were found with regards to the intramuscular fat content and variations in protein and ash content.

Ruminants contain micro-organisms in their gut that have the ability to degrade and utilise cellulose. The rumen condition and the bacteria population involved in the production and accumulation of fatty acids is therefore determined by the composition of the diet consumed. Bacteria produce volatile fatty acids (VFA) in the rumen from specific feed compounds via a series of reactions (Priolo *et al.*, 2001). Therefore, different fatty acid profiles are produced in the meat of animals reared in different production systems as the forages consumed differ and as a consequence the sensory quality of the meat differs (Nuernberg *et al.*, 2005). It has been found that extensive production

systems have a positive effect on the fatty acid composition of certain species at the expense of higher growth rates (Webb & O'Neill, 2008). Thus composition of the diet consumed by animals influences the fatty acid content of their meat.

The concentration of the fatty acids has an influence on the flavour of the meat produced. Fat tissue of ruminants have higher proportions of saturated fatty acids (SFA) and lower polyunsaturated fatty acids (PUFA) than in monogastric animals (Webb & O'Neill, 2008). The effect of diet in ruminants on the fatty acid profile produced is not as pronounced as in monogastric animals because ruminants consume diets of lower lipid contents and dietary lipids undergo hydrogenation in the rumen (Wood *et al.*, 2004). However there have been dietary effects reported. Hoffman *et al.* (2005) found differences in the fatty acid profiles produced in impala meat that were produced in different regions and grazed/browsed on different diets. In contrast, region did not have a significant influence on the chemical composition of blesbok meat, this was however attributed to the specific grazing behaviour of blesbok who only utilise short grasses, also known as lawns (Hoffman *et al.*, 2009).

Studies have also shown that game meat has substantially higher amounts of PUFA than domestic animals due to the differences in the diets consumed by the animals (Wiklund *et al.*, 2003; Hoffman, Van Schalkwyk & Muller, 2009).

The meat of wild animals that have been grown on grass and herbs in the natural food chain have a high quantity of PUFA, omega-3 (n3) fatty acids and antioxidants (Olsson & Pickova, 2005). Daszkiewicz *et al.* (2015) found that fatty acid concentrations were affected by the origin of the fallow deer, being wild (extensive) or farmed (semi-extensive). The wild fallow deer meat contained higher levels of saturated fatty acids namely, Lauric acid (C12:0) and Arachidic acid (C20:0), where the meat of the farmed deer had a higher quantity of Stearic acid (C18:0) and higher total of SFA. A difference was also noted in the unsaturated fatty acids' concentrations between the two treatments. The wild fallow deer meat has higher quantity of Methyl myristoleate (C14:1), Palmitoleic acid (C16:1), *cis*-11-Eicosenoic acid (C20:1) and the total MUFA content was higher than farmed fallow deer, where higher levels of *cis*-10-Heptadecenoic acid (C17:1), γ -Linolenic acid (C18:3n6) and Arachidonic acid (C20:4n6) were noted. The PUFA/SFA concentration should be higher than 0.4, but in this study for the wild and farmed fallow/.ML deer the PUFA/SFA ratio was a low 0.27.

Fatty acid profile of game meat and other red meat are similar in that the predominant saturated fatty acids are palmitic (C16:0) and stearic (C18:0) acids and the dominant MUFA is oleic acid (C18:1n9c). This was confirmed by Hoffman *et al.* (2005) who reported that the major saturated fatty acids measured in impala from two different regions were myristic (C14:0), palmitic acid (C16:0) and stearic acid (18:0).

2.2.2.2. Pre-slaughter conditions

Care taken during the handling of animals before slaughter is an important factor as it influences the welfare of the animals, meat quality of the final product, carcass shrinkage and safety of the labours (Malmfors & Wiklund, 1996). The control of pre-slaughter factors can result in better sensory and meat quality of the final product. However since game species in South Africa are often wild and free-living and occurring in different habitats (grass plains, mountains, dense vegetation), these factors are not easily controlled. Their survival instincts, which over many years have allowed them to survive in the wild, cause them to often be more prone to stress effects as they react to any external stimuli (Neethling *et al.*, 2016). They undergo a fight or flight reaction during harvesting, which results in an increase the levels of stress associated hormones, influencing meat quality (Hoffman & Wiklund, 2006). This reaction often involves running or injury causing the glycogen levels to be reduced to support muscle activity and therefore the animal has a low muscle energy status at slaughter (Viljoen, De Kock & Webb, 2002). This results in reduced levels of lactic acid post-mortem associated with meat with a high ultimate pH, tough due to a decrease in post-mortem proteolysis, a higher WHC, more susceptible to bacterial spoilage due to an alkaline environment resulting in a reduced shelf-life, dark colour and less pronounced taste which ultimately translates into dark-firm-dry (DFD) meat being produced (Ramanzin *et al.*, 2010; Shange, Makasi, Gouws & Hoffman, 2018).

Studies on reindeer where animals were handled (herded) prior to slaughtering compared to animals that were left undisturbed prior to slaughtering found that undisturbed animals had the lower pH levels post-mortem. The undisturbed animals (shot in the mountains) also had a less unpleasant, strong flavour and odour found sensorial to be associated with the pre-handled animal's meat (Smith & Dobson, 1990; Wiklund, Malmfors, Lundström & Reh binder, 1996). Similarly, Wiklund *et al.* (1996) found that reindeer that have been subjected to pre-slaughter handling, often farmed reindeer, to be associated with a 'stress flavour' in meat with a high pH_U. Wiklund *et al.* (1996) however found that when animals (reindeer) were handled for prolonged periods of time (3 days) using a helicopter to herd them, there was no effect on glycogen stores or the pH_U levels, indicating that the animals became habituated to the new, unknown "stressful" environment and also had time to replenish their glycogen reserves. In southern Africa, most game species are harvested at night to reduce their range of sight and thus stress and shot in the head to minimise carcass damage (Hoffman & Wiklund, 2006).

2.2.3. EXTRINSIC FACTORS AFFECTING RUMINANT MEAT QUALITY DURING AND POST SLAUGHTER

2.2.3.1. Harvesting methods

Game farms are fenced in areas and therefore controlling the game animal population numbers has become an integral part of the management strategies implemented on these farms to ensure the

sustainable animal production and avoid overgrazing of natural resources (Van Schalkwyk, Hoffman & Laubscher, 2011). The defined objective(s) of the farm for stocking game determines which management strategies are implemented to control the animal population. If game animals are produced primarily for game meat production then regular harvesting is done. The technique of harvesting depends on the species, habitat and the vegetation of the area (Van Schalkwyk *et al.*, 2011). The harvesting techniques are continuously adjusted to ensure that the most effective, quick and humane methods are used following strict guidelines after which all parts of the animals are utilised (meat, skin, horns etc.) (Van Schalkwyk, & Hoffman, 2016). Therefore night shooting has become the most popular method to harvest game animals (Hoffman & Wiklund, 2006). Several studies have noted that the least amount of ante-mortem stress is experienced through night shooting which has beneficial effects on certain meat quality parameters (Von La Chevallerie & Van Zyl, 1971; Lewis, Pinchin & Kestin, 1997; Kritzing, Hoffman & Ferreira, 2003; Hoffman & Laubscher, 2009b; 2010; 2011). Day harvesting called culling (selective to specific animals) is also a common method used as it is often less expensive than night harvesting and sometimes the terrain does not allow for night harvesting. This method also allows the marksman to clearly distinguish between sex's as well as age which allows for a more selective culling to be possible (Hoffman & Laubscher, 2009). However this method has an adverse effect, often being associated with large amount of ante-mortem stress which can effect post-mortem pH levels and cause several detrimental effects on several meat quality parameters and shelf-life (Van Schalkwyk, Hoffman & Laubscher, 2011). Another issue with day-light harvesting is the presence of flies and the associated hygiene issues.

Hunting game species in South Africa often involves prolonged driving that increases the time of shooting to dressing. Therefore game animals that are intended for consumption should be bled without delay, preferably within 10 minutes of being shot as blood is the ideal growth medium for bacteria. Also the carcasses should be eviscerated as soon as possible as late removal of the gastro-intestinal tract increases the rate for microbial contamination when intestinal bacteria are allowed to pass through the intestinal barrier and contaminate muscle tissue which can deteriorate the carcass value (Ramanzin *et al.*, 2010). If the abattoir is far from the area of shooting, the removal of intestines and stomach in the field is also encouraged, with care not to contaminate the abdominal cavity and cut surfaces with ruminal content. Removal of the gastro-intestinal track, particularly in larger animals also facilitates the loading and transport of what is now "lighter" carcasses. However to avoid adverse effects to the carcass, it has been proposed that hunts must be interrupted after 1-1.5 hours to allow the dressing of shot animals (Ramanzin *et al.*, 2010).

2.2.3.2. Storage conditions

The period that meat is chilled for in storage and whether or not the meat is frozen is important factors that influence the ultimate meat quality of the meat. Cooling of meat is an essential process

to prevent bacterial growth that causes meat spoilage. The first 24 hours of cooling is also extremely important in reducing the carcass temperature from 37°C to 4°C to allow it to undergo sufficient rigor-mortis (Dransfield, 1994). If the carcass is cooled to a too low temperature then the tenderising enzymes are inactivated which will adversely reduce tenderness by slower rigor development (Wheeler, Savell, Cross, Lunt & Smith, 1990).

In the meat supply chain, freezing has become an unavoidable process due to the constant demand for 'fresh' meat products and to ensure the safety of products supplied to all regions of the world (Wheeler *et al.*, 1990; Leygonie, Britz & Hoffman, 2012). Freezing slows down the rate of ageing by stopping the activity of the calpains, although they are not destroyed by the process, therefore it only halts their activities throughout the storage period (Leygonie *et al.*, 2012). Freezing also prevents microbial growth and spoilage and is therefore a good method of preservation to keep the meat wholesome. However, freezing and thawing has an effect on the quality of the meat, by significantly affecting the water fraction of the meat (Leygonie *et al.*, 2012).

Water is contained within the muscle fibres and therefore, when meat is frozen crystals form within the cells as the intracellular fluid freezes. This causes two major changes to the cell environment. Firstly freezing removes water, causing an increase in the concentration of the remaining meat constituents (protein, lipids, carbohydrates, vitamins and minerals), thus causing disruption to the complex meat system (Lawrie & Ledward, 2006). This promotes protein denaturation which results in an increased moisture loss as well as accelerated protein oxidation that has detrimental changes to meat quality (Leygonie *et al.*, 2012). Therefore, an increase in purge loss has been found when frozen meat is thawed, decreasing the mass of the meat and contributing to the meat becoming visually unattractive to the consumer. Rapid freezing has been shown to cause less denaturation of proteins as well as lower thaw loss than slow freezing and therefore rapid freezing is becoming a common practise in the meat industry (Leygonie *et al.*, 2012). This is because rapid freezing at low temperatures increases the proportion of ice crystals that form intracellularly rather than extracellularly as well as reducing the size of the crystals, making this freezing method less disruptive to the muscle (Leygonie *et al.*, 2012; Muela *et al.*, 2012).

Secondly, the effect of freezing can have a physically disruptive consequence as the ice crystals and the disruption of the connective tissue can rupture cells and cellular organelles (Shanks, Wulf & Maddock, 2002). The extent of the damage depends on the number, distribution, size and morphology of the crystals (Muela *et al.*, 2012). This structural damage causes greater moisture loss however, favourable effects have been associated with freezing (Shanks *et al.*, 2002). Freezing has been shown to increase the tenderness of meat, as meat that has been frozen prior to cooking has measured lower shear force values than fresh meat; it is postulated that the ice crystals cause physical damage to the muscle fibres thereby causing a physical tenderising effect (Shanks *et al.*, 2002; Muela *et al.*, 2012).

Oxidation is a biochemical reaction that occurs in the colour pigments and lipids of meat under post-mortem conditions (Bekhit, Hopkins, Fahri & Ponnampalam, 2013; Neethling, 2016; Neethling *et al.*, 2017). This reaction causes the colour to deteriorate and develop undesirable flavours that are not accepted by consumers. Therefore it is essential that the appearance and meat quality be maintained during the distribution and display of meat products as colour is the most important factor that influences consumer-purchase decisions (Pietrasik, Dhanda, Shand & Pegg, 2006). There is thus a need to package meat in a manner that maintains fresh meat colour stability. It has been shown that meat that is vacuum packed short of freezing is the most effective method used for shelf-life extensive of uncooked meats (Jayasingh, Cornforth, Carpenter & Whittier, 2001). This method of packaging also allows meat to be more compacted and durable during the storage and distribution process.

2.2.3.3. Aging

One of the oldest meat-handling techniques is when meat is aged (Dransfield, 1994). This is a technique used to deliberately optimise product quality and to provide a selling point by holding the meat either on the carcass or as individual cuts, just above its freezing point (e.g. 2-4°C) for a certain period of time before consumption (Lawrie & Ledward, 2006). The optimisation of the quality is primarily aimed at achieving optimum tenderisation of the meat, where improving the flavour is a secondary goal (Lawrie & Ledward, 2006). Aging is influenced by several factors that include storage temperature, oxygen (packaging atmosphere), indigenous enzymes, moisture, light and micro-organisms (Lambert, Smith & Dodds, 1991). Moreover, intrinsic factors such as age, sex, muscle type, anabolic and repartitioning agents, rate of glycolysis, pH_U, sarcomere length, amount and solubility of collagen and post-mortem proteolysis also influence the aging of meat (Koochmaraie, 1994). Another intrinsic factor that has been shown to influence meat quality when aged is breed. Monsón, Sañudo & Sierra (2005) tested the effect of different cattle breeds on the sensory characteristics throughout the aging period. It was observed that breed significantly influenced tenderness, odour and flavour characteristics, with longer aging periods (more than 7 days) reducing the differences between breeds in the textual characteristics. Although the differences between breeds become less as the aging time progresses, breed differences remain (Strydom, Lühl, Kahl & Hoffman, 2016).

Tenderness is the most important organoleptic characteristic considered by consumers. Meat becomes more tender from the time of slaughter, as rigor-mortis resolution is initiated, until consumption as meat has an unique biological and chemical nature that deteriorates progressively as a result of proteolytic action performed by proteinases (Koochmaraie, 1994; Lambert, Smith & Dodds, 1991). This decline in shear force generally involves degradation of the myofibrils and related cytoskeletal proteins that causes these components to weaken. Thus it involves the loss of tissue integrity (improved tenderness) caused by z-disk weakening and myofibril fragmentation caused by

the degradation of desmin and tintin (Koochmaraie, 1994). This degradation has been attributed to a number of factors where the activity of endogenous proteolytic enzymes are regarded as the most important (Nowak, 2011). These enzymes or enzyme systems, if naturally present in the skeletal muscle cells, contribute to tenderisation by degrading proteins and having access to myofibrils (Nowak, 2011). Examples of proteolytic enzyme systems that are thought to fulfil this criteria are calpains, cathepsins, caspases and proteasomes (Nowak, 2011).

The importance of this process has been highlighted by several studies performed to optimise this process, especially in the beef cattle industry, where studies have looked at flavour and textural changes, microbial safety, dry-aged beef, aging in special water-permeable bags and vacuum-packed aging. Studies have found that tenderisation is a finite process as a basal tenderness is reached around 14 days (in beef) after which there is only little improvement found (Monsón *et al.*, 2005). This plateau/maximum tenderness that is reached is attributed to the connective tissue content that is hardly degraded during the aging process (Sentandreu, Coulis & Ouali, 2002; Purslow, 2005).

While tenderness is one of the most important quality traits for consumers, with increased tenderness being associated with greater acceptability, aging also causes changes in colour, aroma and flavour, which is usually associated with undesirable changes (Stetzer, Cadwallader, Singh, McKeith & Brewer, 2008). These are due to chemical changes that occur during aging including protein and lipid oxidation and the denaturation and degradation of proteins (Campo, Sañudo, Panea, Alberti & Santolaria, 1999). These chemical changes influence the nature of the precursor compounds available for the volatile compounds that are formed during the cooking of the meat (Stetzer *et al.*, 2008). Studies that have evaluated the changes in the aroma and flavours produced during aging have noted that when beef is aged for a short to medium term, there is an increase in the overall aroma intensity and the intensity of beef-like, brothy, sweet and brown-caramel aromas and flavour which are all desired by consumers (Monsón *et al.*, 2005). In contrast, beef that has been aged for extensive periods of time has been associated with an increase in liver-like, metallic, gamey, off, rancid, cardboard, bitter and sour attributes that are all considered undesirable (Spanier, Vercellotti & James, 1992; Yancey *et al.*, 2006; Stetzer *et al.*, 2008). These off flavours are due to the production of carbonyls and aldehydes that react to form sulphur-containing peptides during the oxidation of proteins and lipids (Stetzer *et al.*, 2008).

Increased aging period has also been associated with an increase in weep loss, drip loss and cooking loss. It has been noted that a purge loss of 1 to 2% is acceptable; where a purge loss greater than 4% would be excessive and have a negative impact on consumer perception and meat quality of the product (Colle *et al.*, 2015).

Muscle type has an effect on the meat quality during post-mortem aging; Ba *et al.* (2014) aged the LD and ST muscles of Korean beef for 28 days and reported that muscle type had a significant influence on the cooking loss, with the LD muscle having a lower cooking loss percentage.

At 28 days the LD muscle's CIE L* value had increased significantly from that measured at day 7, thus becoming lighter in colour as the aging time increased. The increase in lightness can be explained by the modification of protein structures that cause a higher dispersion of light.

Warner-Bratzler shear force (WBSF) is used to measure the tenderness or toughness of meat (higher WBSF is linked to tougher meat). Ba *et al.* (2014) established that the WBSF values differed between the different muscle types that were aged post-mortem but values decreased as the aging period increased. The LD muscle had significantly lower WBSF values at 28 days of aging than the ST muscle, indicating that the LD muscle was more tender. The ST muscle has a higher amount of collagen than the LD muscle which influences the tenderness directly. No difference between the two muscles was found with regards to the pH measured on day 7 and day 28 of aging, suggesting that glycogen was completely depleted in both muscles by day 7.

The type of muscle subjected to post-mortem aging affects the sensory attributes such as tenderness, juiciness and flavour (Ba *et al.*, 2014). When comparing LD and ST muscles both aged for 28 days, the LD muscle was associated with higher scores for all the above mentioned sensory attributes.

Therefore, the range of changes that occur during aging are both positive and negative, where an ideal balance should be reached to optimise quality. This ideal balance will differ between species, breed, sex, animal and muscle due to differences in the proteolytic potential of the enzyme systems as well as the post-mortem handling of the carcass, as well as the background toughness of the meat prior to aging. Aging of meat is also an extremely variable process as it depends on the temperature and duration of storage.

2.3. CHARACTERISATION OF BLUE WILDEBEEST

This species of wildebeest seems to have evolved around 2.5 million years ago, whilst it diverged from the black wildebeest to become a distinct species around a million years ago (Hilton-Barber & Berger, 2004). Today the blue wildebeest (*Connochaetes taurinus*) is one of the larger bushveld mammal species found in South Africa and has become a popular addition to all forms of game farming (Furstenburg, 2002). These animals are widely distributed in South Africa and have an annual population increase of 29 to 35% and therefore the demands for meat production can easily be met (Furstenburg, 2002).

Physically defined by having large heads with both males and females exhibiting horns that are relatively close together at the base, curving outward, inward and then curving slightly backwards (Bothma, 2013). They also have large forequarters and can reach a length of about 2.4 m, 1.4 m tall at shoulders and can weigh up to 272 kg, having manes with long hair and a whisk at the tip of the tail (Bothma, 2013). They have adapted to their environment structurally and behaviourally by developing strong leg muscles for long migratory periods as well as physiologically, with a rumen stomach to help digest cellulose in grass and teeth to grind grass.

Wildebeest are classified as bulk and roughage eaters due to their high preference for fresh grass and large quantities of water (Estes, 1991). They are grazers and prefer a habitat of savanna woodlands where they graze on short grasses. They are very selective when it comes to eating habits and rarely eat grasses that are taller than 150 mm and will select green sprouts from plants after a fire has occurred. However the selection of grasses tends to change with season and availability but browse tend to make up about 13 percent of their diet (Bothma, 2013). Therefore habitat consisting of sour veld is not suitable for them as they have a muzzle that is well adapted to grazing close to the ground (Bothma, Van Rooyen & Du Toit, 2010).

Blue wildebeest require a habitat that provides adequate shade, as in the wild they are seldom found more than 100 m away from the nearest shade, and around areas where water is permanently available (Bothma *et al.*, 2010). They cannot go without water for longer than a few days (Meyer & Casey, 2010). They drink around nine litres of water a day and drinking appears to be most active during early morning and they show preference for natural waterholes (Bothma, 2013).

Both the males and females become sexually mature at 16 months of age but bulls will only mate once they have become territorial. In an extensive environment the bull to cow ratio that is recommended for optimum production is 1:6 to 1:10, so that there are six to ten cows per bull (Bothma *et al.*, 2010). Once mating has occurred (March-May) and the cow is pregnant, gestation will occur for a period of nine months (250 days). At the end of gestation (November to December), a single calf is born often weighing around 16 to 22 kg. Unlike other antelope game species calving occurs amongst the rest of the herd members (Estes, 1976). Immediately after birth (within 3 to 7 minutes) the calves are mobile and able to run along with their mothers, thus they are defined as being follower young (Estes, 1976). Within the first 10 days the calf starts nibbling on grass even though it is only weaned at 8 months old. The calves remain at their mothers' side until the next calf is born, after which the males are pushed out the herd to go start their own harems (a group of female animals sharing a single male animal), but the females often remain in the same herd as the mothers throughout their entire life (Walker, 1996).

These animals have shown to be hardy, highly adaptable, fertile and resistant to most tropical diseases (Furstenburg, 2002). Therefore, they have become very popular addition to all forms of game farming, becoming one of the most preferred hunting species among the biltong and trophy hunters (Van der Merwe, Scholtz & Saayman, 2011). Often the primary aim of farming these animals are thus to produce high quality animals for live-sale, trophy hunting or used in the breeding of golden wildebeest (Gnu). Golden wildebeest are a naturally occurring colour variant and not a sub-species of the blue wildebeest; farmers have made use of behaviour manipulation to breed animals for these selected traits (hide colour). Therefore, the numbers of this species has grown substantially with the success of breeding this colour variant although there are also other groups such as the "crowned/kings" wildebeest that typically are the natural 'blue' colour but have a golden

head/crown. Frequently, during the breeding of these colour variants, hybrids as well as coloured animals (mainly bulls) that do not meet the breeding/stud selection criteria (normally due to inferior horns and/or body conformation) are available for hunting or slaughter. Therefore in these production systems good management practises such as regular culling of surplus or sub-standard stock, mainly bulls, especially in golden wildebeest breeding programs as to allow bulls of a specific colour and conformation to become dominant, are practiced (Bezuidenhout, 2012). This has resulted in adequate numbers of blue wildebeest, especially bulls, being available for meat production.

2.4. CONCLUSION

The availability of meat from game animals is rapidly increasing in South Africa due to the continuous growth of the game industry. Meat from these animals is associated with favourable nutritional properties due to its low fat content and fatty acid profile. This meets the quality criteria that is currently being demanded by consumers. However, due to the variation in species, vegetation and farming production systems associated with game species in South Africa, species-specific research should be a priority.

Blue wildebeest are known to be hardy, highly adaptable, fertile and resistant to most tropical disease and therefore numbers are increasing rapidly on privately own farms. On these privately owned farms they are being subjected to all of the different forms of production systems, mainly extensive and semi-extensive and intensive. Thus there are variations in forage consumed and physical activity of the animals that may present in the chemical, physical and sensorial quality of blue wildebeest meat.

As far as it could be ascertained, a limit amount of information exists on the meat quality characteristics of the blue wildebeest and none on the effect of different feeding regimes on this quality. To successfully market game species, locally and internationally, it is important that scientifically correct information on the quality and nutritional value of a specific meat product is determined.

This research will therefore look at the influence of different production systems (differing in feed composition and feed intake) as well as evaluating the influence of different ages and muscle types on the meat production (yields) and meat quality (physical parameters, chemical composition and sensory profile) of this species. In addition, the optimum aging period required to produce meat products of optimum tenderness will also be determined. Therefore, the study will provide an overview of the meat quality of this species to provide a reliable baseline for the producers in the game meat industry and highlight research areas that require further investigation.

2.5. REFERENCES

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CHAPTER 3

INFLUENCE OF PRODUCTION SYSTEM ON THE CARCASS YIELD OF BLUE WILDEBEEST (*Connochaetes taurinus*)

ABSTRACT

The aim of this study was to generate baseline data on the meat production potential of blue wildebeest bulls from contrasting production systems, as well as their consumable offal yields. Eight blue wildebeest bulls were culled from a semi-extensive production system and eight similarly aged bulls from an extensive system where animals were subjected to different diets. Semi-extensive wildebeest had significantly higher undressed carcass weights (208.2 ± 11.14 kg) and dressed carcass weights (112.1 ± 6.38 kg) than the extensive (168.8 ± 14.59 kg and 84.9 ± 7.55 kg, respectively) blue wildebeest. Similarly for the dressing percentage (53.8% and 50.2%, respectively), which was comparable to or higher than other antelope and domestic livestock species. Semi-extensively raised blue wildebeest also showed higher weights for external and internal offal parts than those from the extensive system. The results obtained in the study show that a semi-extensive farming system has the potential to increase the carcass yield of blue wildebeest bulls.

Keywords: Production system, Blue wildebeest, Carcass yields, Offal yields

3.1 INTRODUCTION

Within the next 35 years Africa needs to double its food production to avoid food shortages brought on by the ever-growing human population, increase in desertification caused by climate change and overgrazing of suitable land (Asibey, 1974; Dry, 2012). Malnutrition and famine are conditions that are already pronounced in these developing countries due to the lack of available protein sources (Bwibo & Neumann, 2003). Protein plays an important role in human diets, supplying essential nutrients to improve maternal health and early child development (Bwibo & Neumann, 2003). Therefore several attempts have been made to counteract the protein deficiency problem, mainly by importing protein-rich foods. South Africa consumes about 2.9 million tons of meat per year (excluding game meat), while only 2.4 million tons is produced locally by livestock producers, therefore in order to fulfil the needs of the population, the shortage is complimented by imports (Torry, 2015). However, the burden of exchange rates have made this solution difficult as the strength of the economy limits what can be imported, often resulting in low income families being unable to afford imported products. Therefore, it has become important to evaluate local protein sources that can be utilised efficiently and are hopefully more available and affordable to local consumers (Cooper & van der Merwe, 2014). Game farming offers the practical solution for meat production as it provides the much needed animal protein that will improve food security while being economically sustainable and maintaining biodiversity (Hoffman & Cawthorn, 2012).

The game industry in South Africa has grown significantly in magnitude and diversity in the last two decades. It is estimated that this agricultural sector covers more than 20 million ha of land, which makes up 16.8% of the total grazing land in South Africa (Otieno & Muchapondwa, 2016). There is an average of 10000 game ranches and more than 4000 mixed game and livestock farms registered, with an additional 6000 unregistered farms (Taylor, Lindsey, & Davies-Mostert, 2016). This significant shift from conventional stock farming to game farming, is largely as a result of game farming proving to be more economically viable (generates higher net farm revenues) than livestock farming in the dry regions of sub-Saharan Africa (Berry, 1986; Otieno & Muchapondwa, 2016). South Africa is already one of the most water stressed countries in Africa and with the additional effects of climate change and increased weather variability there are concerns about the future of livestock farming (Otieno & Muchapondwa, 2016). Game animals are able to utilise natural vegetation more efficiently than livestock due to their low nutritional requirements and ability to efficiently use available vegetation developed through centuries of adaptation to the diverse and harsh environmental conditions of South Africa (Muir, 1989; Cole, 1990). They have developed physiological and behavioural water conservation mechanisms allowing them to be less water dependent, have higher meat percentage in relations to body weight due to less fat content and are generally disease resistant when compared to conventional domestic livestock species (Von La Chevallier & Van Zyl, 1971; Muir, 1989; Cole, 1990). This has resulted in an 40 fold increase in wildlife since 1960 being

found on privately owned wildlife ranches, of which 6 million are estimated to be large herbivores (Taylor, 2016).

The game industry has developed into a highly profitable industry being driven by diverse income opportunities. Income is generated from legal trade, recreational and professional hunting, eco-tourism and meat production (Bothma & Van Rooyen, 2005). Therefore, farming with game animals is a low-input and multi-purpose form of farming. The popularity of this type of farming has resulted in the development of various combinations of intensive, semi-extensive and extensive systems to optimise animal production. Intensive farming is where highest production is achieved on the smallest possible land area making use of strategic supplementary feeding and breeding programs (Taylor *et al.*, 2016). Semi-extensive farming involves keeping the animals in camps large enough to allow free movement but regular management intervention is practiced to optimize production and health. Similar to intensive farming the animals are subjected to strategic supplementary feeding, breeding programs and water provision (Oberem & Oberem, 2016). Thus intensive and semi-extensive production systems provide animals with optimum nutrition all year round with little or no predation and disease stress. In an extensive system animals are left to roam freely with little or no additional inputs relative to the size of the land with the exception during times of drought. Therefore the level of activity and forage consumed by game species differs between the production systems and thus their development and growth. This all causes changes in both the intrinsic and extrinsic aspects of the carcass and meat quality (Webb & Erasmus, 2014; Hoffman, Kroucamp & Manley, 2007).

Amongst the game species that have become a popular addition to all forms of game farming is the blue wildebeest, one of the larger antelope found in South Africa with adult bulls reaching 250 kg mass and a shoulder height of 1.5 m. In 2014 it was calculated that blue wildebeest was one of the species with the highest ecological biomasses (9.4%) in South Africa (Taylor *et al.*, 2016). These animals are known to be hardy, highly adaptable, fertile and resistant to most tropical disease and therefore numbers are increasing rapidly on privately owned farms (Furstenburg, 2002). In many cases the primary aim of farming with these animals are to produce high quality animals for live-sale, trophy hunting or used in the breeding of golden wildebeest (*Gnu*). Golden wildebeest is a naturally occurring colour variant and not a sub-species of the blue wildebeest, as the golden coat colour is thought to be caused by the expression of a recessive gene where the blue colour is simply the expression of the gene in its dominant form. However it is more complex than the expression of a single recessive gene as a split bull (containing the colour gene) crossed with a split cow does not give the classical 3:1 ratio as would be expected from a single recessive gene. Regardless a golden blue wildebeest and a blue wildebeest are exactly alike in physical, biological, habitat and social characteristics differing only with regards to the physical colour appearance, which has shown to have no negative implications on the animal, but could possibly be advantageous. The advantageous factor, however not yet quantified, is that the golden coat colour could allow the animal to possibly

adapt better to warmer climates than their blue counterparts due to the lighter colour causing less radiation absorption (Smith, 2013). In order to produce animals of perfect health and optimum condition, good management practises are essential. This often includes the regular culling of surplus or sub-standard stock, mainly males, especially in golden wildebeest breeding programs (the bull splits are normally culled), thus these male animals are available for meat production (Bezuidenhout, 2012).

Before an animal can be considered for meat production, essential information must be available in terms of carcass yields, nutritional composition and consumer acceptability in order for it to compete with meat from existing domestic livestock (Hoffman, Muller, Schutte, Calitz & Crafford, 2005; Hoffman & Cawthorn, 2013). Game meat is generally sold per animal or per kilogram and therefore it is essential to know the dressing percentage and meat yields obtained from a particular animal species (Hoffman & Wiklund, 2006). The information on the yields should include most or all edible portions of a carcass and therefore data should also be generated on the yields of consumable organs. Currently there is little data available on the carcass and meat quality characteristics of blue wildebeest, with no data available on the influence of different production systems in which this species is currently being raised. The aim of this study was thus to generate baseline data on the meat production potential of blue wildebeest from different production systems, while also looking at the consumable organ yields. This will give insight into whether blue wildebeest could be considered as a viable complementary or alternative source of animal protein.

3.2 MATERIALS AND METHODS

3.2.1 Animals and study location

A total of 16 blue wildebeest (*Connochaetes taurinus*) bulls (age 16 months to >4 years) were obtained from two different production farming systems situated in the Modimolle region in the Limpopo province, South Africa in March 2016. The region forms part of the Savanna biome, with grassland plains filled with grassy ground layer, dense cluster of trees and tall shrubs. The region has an elevation that varies from 750 to 1.400 m and has an annual rainfall of 350 mm to 600 mm (Mucina & Rutherford, 2006).

Eight animals were randomly culled from an extensive production system, Bushlovers lodge (S 24°39,056 E 28°22,852), that grazed natural vegetation while roaming freely. Both bulls and cows roamed together. The farm is located in the Waterberg Mountain bushveld characterised by rugged mountains with vegetation ranging from *Faurea saligna* and *Protea caffra* trees on higher slopes to broad leaved deciduous bushveld (trees and shrubs that shed leaves annually) on the foot slopes with a grass layer that is moderately to well developed (Mucina & Rutherford, 2006). Animal age was determined using tooth eruption.

Eight additional animals were then selectively (according to age) culled from a semi-extensive production system situated in the Central Sandy bushveld vegetation unit, Sandstone

valley (S 24°33,764' – E 26°02,510'). These animals were blue wildebeest splits which are individuals that carry the genes for the recessive colour. This veld type is characterised with gentle sloping hills and hallows found between mountains and sandy plains with tall woodland trees. It has a grass-dominating herbaceous layer with relatively low basal cover on dystrophic sands (Mucina & Rutherford, 2006). Animals ($n \sim 300$) were maintained in a breeding camp of approximately 600 ha, consisting of only bulls, and fed a daily ration of 3 kg/animal strategic supplementary feed. The formulation of the supplementary feed (mixed using a on-farm mixer to form a homogenous ration) at point of harvest was: grass (33.99%), maize (15.69%), Brewers grain (12.5%), molasses (12.55%), soya oil cake (7.32%), wheat (6.24%), cotton oil cake (5.23%), Lucerne (3.92%), lime (0.94%), phosphate trace-mineral supplement - high in monocalcium phosphate - (0.94%), mineral premix (0.34%), and salt (0.26%). This typical diet varies with regards to availability of the main ingredients. The two farms were approximately 45 km from each other.

Table 3.1 illustrates the layout of the animals obtained according to production system and age to determine their effect on carcass yields. The extensive animals were shot first, where after the semi-extensive animals were selected to be as close to the same age as the extensive animals. However because of the specific farming system, no animals older than 40 months were found in the semi-extensive system. Eight adults bulls characterised as being reproductive (sexually mature) and eight sub-adults that have not yet reach reproductive maturity were culled (Bothma, Van Rooyen & Du Toit, 2010). Blue wildebeest bulls reach sexual maturity at about two years of age and therefore an adult bull was defined here to be older than 28 months (Estes, 1991).

Table 3.1 Distribution of animals obtained according to production system and age to determine the effect on carcass yields.

Age		Production system		Total
		Extensive	Semi-extensive	
Sub-adult	16 months	4	3	8
	28 months	0	1	
Adult	40 months	0	4	8
	>4 years	4	0	
Total		8	8	16

3.2.2 Culling and dressing

All animals were culled during the day using a 0.308 calibre rifle with a sound suppressor by a marksman on the back of a secure hunting vehicle. All animals were shot in the head, which is the requirement for game production that is destined for export, as this has been shown to be associated with the least damage and wastage of the carcass as well as avoiding contamination with intestinal, ruminal or blood content (Van Schalkwyk & Hoffman, 2016). After shooting, all animals were immediately exsanguinated. In the field, the time shot and details about the shooting were recorded.

The animals were then loaded on the back of the culling vehicle and transported to the slaughtering facilities.

Upon arrival at the slaughtering facility, the “live” mass (undressed carcass weight) was measured by weighing the undressed, exsanguinated warm carcass of the animal using a calibrated hanging scale. The head, skin and legs (external offal) were removed, weighed and evisceration was done as according to Van Schalkwyk & Hoffman (2016). As wildebeest bulls are ultimately bred for trophy (trophy status determined by horn size) hunting, the horns were measured in inches as is done in the industry using a flexible $\frac{1}{4}$ inch plastic measuring tape (Schwabland & Barnhart, 2016). Both the left and right base and horn lengths were measured, as indicated in Figure 3.1, as well as the total length from the tip of the right horn moving down the outside of that horn following along the curl and up to the base then continued straight across the forehead following the same path all the way up to the tip of the second, left, horn. Internal organs were also removed and weighed. The dressed warm carcass was stored overnight in a cold room at 4°C to undergo rigor.

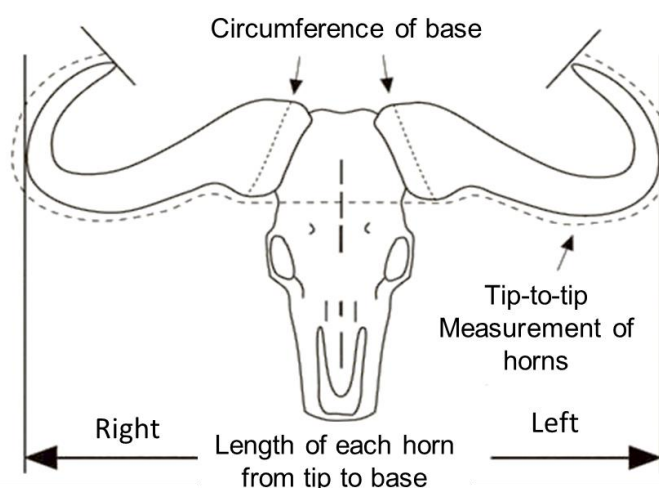


Figure 3.1 Diagram illustrating how the horns lengths (in inches) of each individual blue wildebeest bull was measured, adapted from Schwabland & Barnhart (2016).

3.2.3 Sample preparation

After ~24 hours of cooling, the cold carcass was weighed and shoulder muscles *infraspinatus* (IS) and *supraspinatus* (SS); hind limb muscles *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST) were removed in their totality and the *longissimus thoracis et lumborum* (LTL) removed from between the last lumbar vertebra and the natural termination of the muscle at the cervical vertebra (Fig 3.2). Muscles from both the left and right side of the carcass was removed and weighed.

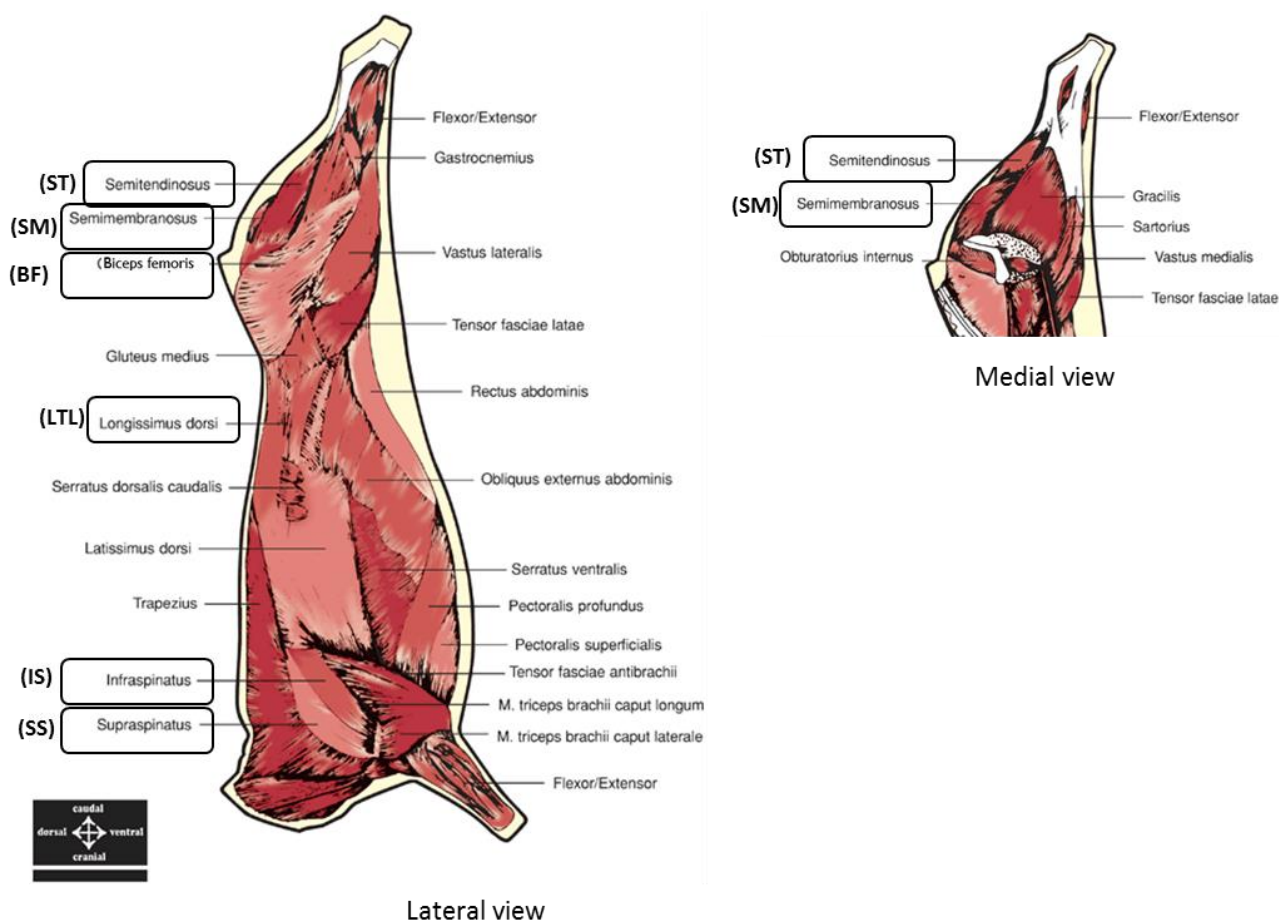


Figure 3.2 The lateral view of the anatomical location of the six muscles removed for analyses, with a medial view showing the ST and SM for clarity, adapted from Aus-Meat (2005).

3.2.4 Statistical analyses

The experimental design was a completely random factorial with eight animals harvested at random from each production system (extensive and semi-extensive; $n = 16$) and two age groups (adult and sub-adult). The carcass, offal and muscle weights were analysed by performing univariate analysis of variance (ANOVA) using the General Linear Models (GLM) procedures of SAS software (Version 9.4; SAS Institute Inc., Cary, USA). The two main effects were production system (extensive and semi-extensive) and age (adults and sub-adults) with animals being the random repetitions; 5% significant level was set as a guideline for determining significant effects.

A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). Where there was significant deviation from normality, such when the standardised residual for an observation deviated with more than three standard deviations from the model value, outliers were evaluated and where applicable, removed.

To compare the means, a Fisher's t-least significant difference was calculated (Ott, 1998). A 5% probability level was considered significant for all tests testing significance. The values are reported as the Least Square Means and standard error. Correlations were quantified by means of the Pearson's Correlation coefficient.

3.3 RESULTS

3.3.1 Carcass yields

Carcass yield was measured to determine the meat production potential of blue wildebeest bulls from the different production systems. No significant interaction was observed between the production systems and age groups with regards to undressed carcass weight, carcass weight and dressing percentage. There were differences ($p \leq 0.05$) observed for the mean undressed carcass weights between the extensive and semi-extensive production systems as well as the adult and sub-adult age groups (Table 3.2). The mean undressed carcass weight for the extensive system was significantly lower (168.8 ± 14.59 kg) than for the semi-extensive system (208.2 ± 11.14 kg). For the adult age group the mean undressed carcass weight was significantly higher (211.15 ± 8.93 kg) than for the sub-adult age group (165.9 ± 14.89 kg).

Highly significant differences were observed for carcass weight between the different pooled production systems and pooled aged groups. The mean carcass weight for the extensive system was 84.9 ± 7.55 kg, lower ($p = 0.003$) than the 112.1 ± 6.38 kg observed for the semi-extensive production system. The adult age group again had a higher ($p = 0.005$) mean carcass weight (111.3 ± 5.97 kg) than the sub-adult age group (85.7 ± 8.24 kg). The extensive system had a lower ($p < 0.0001$) mean dressing percentage ($50.2 \pm 0.34\%$) than that of the semi-extensive ($53.8 \pm 0.49\%$) system (Table 3.2). A difference ($p \leq 0.05$) was also observed between the age groups with the adult group having a higher dressing percentage ($52.6 \pm 0.91\%$) than the sub-adult group ($51.5 \pm 0.57\%$).

Table 3.2 LSMeans carcass yields (\pm standard errors) and p-values for different production systems and age groups of blue wildebeest bulls.

Carcass yields		Production system		p-value
		Extensive system	Semi-extensive system	
		(n=8)	(n=8)	
Undressed carcass	kg	168.8 \pm 14.59	208.2 \pm 11.14	0.015
Carcass weight	kg	84.9 \pm 7.55	112.1 \pm 6.38	0.003
Dressing percentage [#]	%	50.2 \pm 0.34	53.8 \pm 0.49	<0.0001
		Age		p-value
		Adult	Sub-adult	
		(n=8)	(n=8)	
Undressed carcass	kg	211.2 \pm 8.93	165.9 \pm 14.89	0.007
Carcass weight	kg	111.3 \pm 5.97	85.7 \pm 8.24	0.005
Dressing percentage [#]	%	52.6 \pm 0.91	51.5 \pm 0.57	0.050

[#] The percentage of the live animal weight which is the carcass as determined by dividing the hot-carcass-weight by the live animal weight.

3.3.2 Offal yields

There was a significant interaction observed between the production systems and age groups with regards to the percentage contribution to the undressed carcass weight of the following offal parts; head complete with tongue and horns ($p = 0.019$), skin ($p = 0.027$), GIT ($p = 0.004$), total organs ($p = 0.002$) and the total offal ($p = 0.003$) (Figure 3.3). The highest percentage contribution to the undressed carcass weight of the head was observed for the extensive sub-adult group (8.1%) that differed significantly from the semi-extensive sub-adult group (6.8%), the latter having the lowest percentage contribution. For the skin the lowest percentage was observed for the extensive sub-adult group that was significantly different from the other three treatments; the latter did not differ significantly from each other.

The GIT (Gastro Intestinal Tract composed of stomach and intestines), had the lowest percentage contribution of the undressed carcass weight in the semi-extensive adult group ($19.3 \pm 0.33\%$, 32.7 ± 2.02 kg), differing ($p = 0.004$) from the other treatments; the latter not differing significantly from each other. Similar findings were observed for the percentage of the total organs (heart, lungs, liver, kidneys, spleen and GIT). The total offal percentage, which includes all the offal, was highest in the extensive animals with the age groups not differing significantly (adult = $45.7 \pm 0.45\%$, 91.8 ± 2.29 kg; sub-adult = $45.6 \pm 0.63\%$, 62.2 ± 6.47 kg). The lowest percentage was observed for the semi-extensive adult treatment ($40.7 \pm 0.49\%$, 89.9 ± 3.01 kg) differing significantly from the semi-extensive sub-adult group ($41.2 \pm 0.31\%$, 86.4 ± 9.10 kg), and the extensive system treatments, respectively.

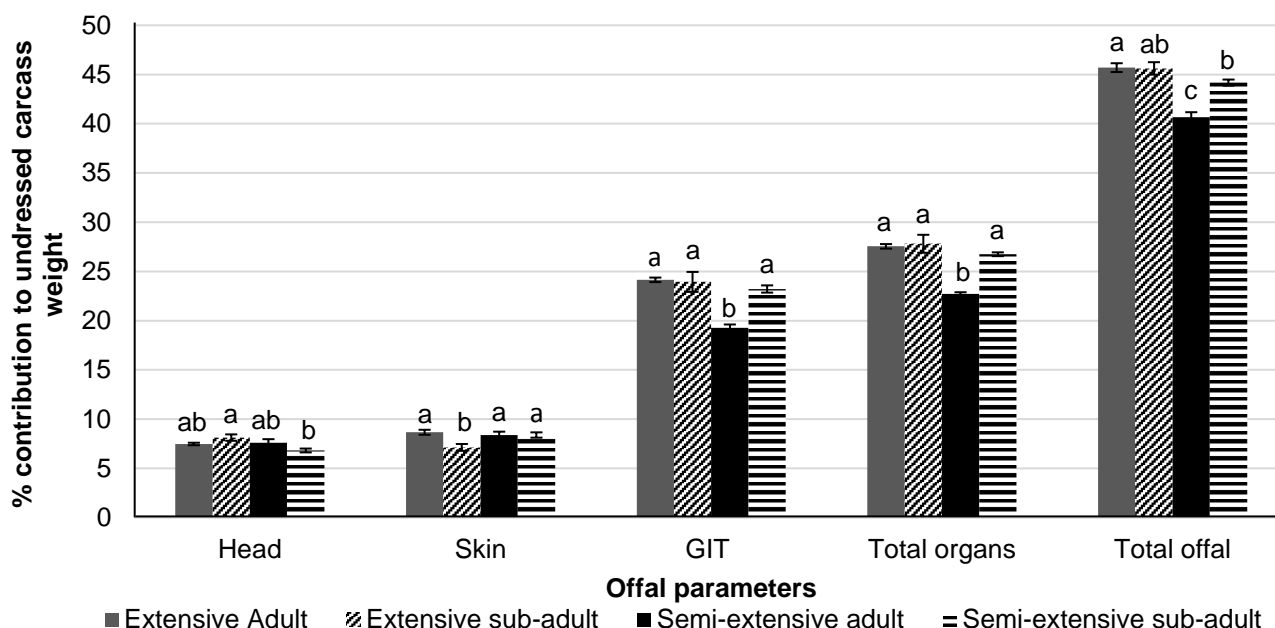


Figure 3.3 Interactions ($p \leq 0.05$) between production systems and age groups for the percentage contribution of the head (tongue and horns), skin, GIT, total organs and total offal to the undressed carcass weights. GIT includes stomach and intestines. Total organs include: heart, lungs (including trachea), liver, kidneys, spleen and GIT. Total offal includes: head, legs, skin and total organs. Values given as Least Square Means and standard error bars. Means with different superscripts differ significantly at $p \leq 0.05$ between the different treatments for each offal part.

Blue wildebeest external offal yields and internal organ yields are presented in Table 3.3. Significant differences ($p \leq 0.05$) were observed between production system and age groups for various offal parts, highlighted in bold. Significant differences between production systems were observed in the contribution of the head (%) to the undressed carcass weight with a higher percentage being associated with the extensive system (7.8%), no difference in head weight (kg) was seen between systems. A significant difference between the weight of the legs and skin were also observed, the heavier weight found in the semi-extensive system. A significant difference in the contribution of the legs to the live weight was observed with higher contribution (%) found in the extensive system.

Table 3.3 LSMeans (\pm standard error) of offal contributions (kg and %) of blue wildebeest bulls as influenced by production system and age (n=16). Significant differences are highlighted in bold ($p \leq 0.05$).

Offal		Production system		p-value	Age		p-value
		Extensive system	Semi-extensive system		Adult	sub-adult	
Undressed carcass	kg	168.8 \pm 14.59	208.2 \pm 11.14	0.015	211.2 \pm 8.93	165.9 \pm 14.89	0.007
Head ^{#2}	kg	13.0 \pm 0.89	15.1 \pm 1.04	0.065	15.9 \pm 0.72	12.2 \pm 0.85	0.003
	% ^{#1}	7.8 \pm 0.20	7.2 \pm 0.24	0.048	7.6 \pm 0.18	7.5 \pm 0.30	0.798
Legs	kg	3.7 \pm 0.18	4.3 \pm 0.12	0.014	4.20 \pm 0.14	3.9 \pm 0.21	0.136
	%	2.3 \pm 0.11	2.1 \pm 0.07	0.045	2.0 \pm 0.20	2.4 \pm 0.31	0.0003
Skin	kg	13.6 \pm 1.64	17.5 \pm 1.07	0.016	17.9 \pm 0.72	13.1 \pm 1.66	0.005
	%	7.9 \pm 0.35	8.4 \pm 0.21	0.149	8.5 \pm 0.21	7.8 \pm 0.31	0.032
Total external offal	kg	30.4 \pm 2.68	36.9 \pm 2.10	0.022	38.0 \pm 1.41	29.2 \pm 1.63	0.0038
	%	18.0 \pm 0.28	17.7 \pm 0.33	0.546	18.1 \pm 0.32	17.6 \pm 0.29	0.349
Heart	kg	1.0 \pm 0.07	1.4 \pm 0.13	0.014	1.3 \pm 0.11	1.0 \pm 0.12	0.045
	%	0.6 \pm 0.04	0.7 \pm 0.03	0.391	0.6 \pm 0.05	0.6 \pm 0.03	0.736
Lungs	kg	2.3 \pm 0.16	2.8 \pm 0.14	0.028	2.8 \pm 0.11	2.3 \pm 0.18	0.024
	%	1.4 \pm 0.08	1.4 \pm 0.09	0.074	1.3 \pm 0.07	1.4 \pm 0.09	0.435
Liver	kg	1.9 \pm 0.08	2.1 \pm 0.10	0.326	2.1 \pm 0.09	1.9 \pm 0.08	0.072
	%	1.0 \pm 0.07	1.0 \pm 0.04	0.025	1.0 \pm 0.04	1.2 \pm 0.08	0.046
Kidneys	kg	0.3 \pm 0.01	0.4 \pm 0.12	0.027	0.4 \pm 0.01	0.3 \pm 0.01	0.007
	%	0.2 \pm 0.01	0.2 \pm 0.01	0.076	0.2 \pm 0.01	0.2 \pm 0.01	0.106
Spleen	kg	0.4 \pm 0.03	0.6 \pm 0.04	0.001	0.6 \pm 0.05	0.5 \pm 0.05	0.188
	%	0.3 \pm 0.02	0.3 \pm 0.02	0.139	0.3 \pm 0.03	0.3 \pm 0.01	0.406
GIT ^{#3}	kg	40.7 \pm 3.69	44.0 \pm 2.63	0.363	45.7 \pm 2.32	39.1 \pm 3.59	0.094
	%	24.1 \pm 0.43	21.3 \pm 0.79	0.004	21.7 \pm 0.90	23.6 \pm 0.52	0.007
Total internal offal	kg	46.6 \pm 3.94	51.3 \pm 2.74	0.241	52.8 \pm 2.29	45.1 \pm 3.88	0.063
	%	27.7 \pm 0.39	24.7 \pm 0.77	<.0001	25.2 \pm 0.92	27.3 \pm 0.48	0.009
Total	kg	77.0 \pm 6.56	88.1 \pm 4.49	0.092	90.8 \pm 3.25	74.3 \pm 3.97	0.019
	%	45.7 \pm 0.33	42.4 \pm 0.73	<.0001	43.2 \pm 1.00	44.9 \pm 0.41	0.004

^{#1}Variable % = contribution to the undressed carcass weight. ^{#2}Head= includes tongue and horns. ^{#3}GIT= Gastro-intestinal tract, includes stomach and intestines.

For the internal organ yields a significant weight difference was reported for heart, lungs, kidneys and spleen; the heavier weights being found in the semi-extensive system. A significant difference in the percentage contribution to the undressed carcass weight was seen for the liver and GIT, with higher percentages seen in the extensive system. Overall there was a significant difference in offal contribution to undressed carcass weight between production systems; higher in the extensive system, however, there was no significant difference in the weight (Table 3.3). The total weight for all of the offal was higher in the animals of the semi-extensive system.

Between the age groups, significant differences were observed for head and skin weights, with heavier weights seen in adult blue wildebeest bulls (Table 3.3). A significant difference in the percentage contribution of the legs and skin to undressed carcass weight was also observed; a higher contribution of legs was seen in sub-adults, with the opposite found for the skin percentage. For the organs there was a significant difference in the weight of the heart, lungs and kidneys, with the heavier weights seen in the adults. On the other hand, a significant difference in the contribution of the liver and GIT were seen with higher percentages for the sub-adults. For all the offal parts measured except for the skin, the higher percentage contribution to the undressed carcass weight was seen in the sub-adult age group, with adults having the higher total offal weight.

Linear correlation coefficients between undressed carcass weights and the offal parts are presented in Table 3.4. There is a direct correlation between undressed carcass weight and all the offal parts. This indicated a general increase in the offal weights with an increasing undressed carcass weight.

Table 3.4 Pearson linear correlation coefficients between undressed carcass weights and the offal parts.

Offal parts	Correlation matrix (Pearson (n-1))	p-value
	r	
Head	0.920	*
Legs	0.892	*
Skin	0.960	*
Heart	0.770	*
Lungs	0.579	**
Liver	0.740	*
Kidneys	0.852	*
Spleen	0.649	**
GIT	0.872	*

* < 0.001, ** < 0.05

Abbreviation: GIT= Gastro-intestinal tract

3.3.3 Horn measurements

The mean horn measurements are presented in Table 3.5. There was no significant interactions between the main treatments (production systems and age) for the different horn measurements. For the production system comparison for all the horn measurements, the longer measurements was associated with the semi-extensive production system, with a significant difference found in the left horn length and the total length between the different production systems. Differences between the adult and sub-adult aged blue wildebeest bulls were found in the left ($p = 0.040$) and right ($p = 0.028$) base lengths, with the longer measurements being associated with the adult group.

3.3.4 Muscle yields

The weights of the six selected muscles (right and left sides) are presented in Table 3.6. No significant interaction was observed between production system and age for any of the individual muscles studied. Significant differences between production systems in the weights (kg) of the LTL, BF, SM and ST muscles were observed. In all these individual muscles the heavier muscle was associated with the semi-extensive production system. However, no significant differences were found between the weights (kg) of the IS and SS muscles between the different production systems. Similarly there was a significant difference in the weight (kg) of the LTL, BF, SM and ST but not IS and SS muscles between the two age groups (adult and sub-adult). Those individual muscles that differed significantly were heavier in the adult age group. For all the treatments, the LTL, BF and SM were the heavier (kg) muscles, while the ST, IS and SS had lower weights (kg). A significant difference was observed between the production systems and age groups for the total muscle yields. Significantly the total weight was higher in the semi-extensive and adult bulls. Nonetheless, no differences between the treatments was seen in the contribution of the aforementioned muscle weights and total weights to the cold carcass weights (Table 3.6).

Table 3.5 LSMean horn measurements (inches) (\pm standard error) for the blue wildebeest bulls as influenced by production system and age. Significant differences are highlight in bold ($p \leq 0.05$).

Horn measurements	Production system		p-value	Age		p-value	Production system*age				p-value
	Extensive	Semi-extensive		Adult	Sub-adult		Extensive adult	Extensive sub-adult	Semi-extensive adult	Semi-extensive sub-adult	
Left base	11.8 \pm 0.26	13.0 \pm 0.61	0.056	13.0 \pm 0.46	11.8 \pm 0.46	0.040	11.9 \pm 0.22	11.8 \pm 0.52	14.2 \pm 0.23	11.8 \pm 0.85	0.051
Right base	11.6 \pm 0.40	12.6 \pm 0.58	0.110	12.8 \pm 0.36	11.3 \pm 0.53	0.028	12.1 \pm 0.33	11.0 \pm 0.69	13.6 \pm 0.25	11.6 \pm 0.90	0.440
Left horn length	19.8 \pm 1.11	22.0 \pm 1.25	0.039	21.0 \pm 1.40	20.8 \pm 1.40	0.807	19.7 \pm 1.67	19.9 \pm 1.55	22.3 \pm 0.81	21.6 \pm 2.43	0.661
Right horn length	19.9 \pm 0.58	21.5 \pm 0.66	0.122	20.9 \pm 0.73	20.4 \pm 0.76	0.612	19.9 \pm 0.87	19.9 \pm 0.89	21.9 \pm 0.63	21.0 \pm 1.17	0.658
Total length [#]	46.8 \pm 0.60	50.8 \pm 0.64	0.046	48.7 \pm 0.70	48.9 \pm 0.66	0.909	45.9 \pm 1.03	47.8 \pm 0.80	51.6 \pm 0.63	50.1 \pm 1.07	0.338

[#]Total length: Measurement started on the tip of the left horn along the horn thread, across the base, to the tip of the right horn.

Table 3.6. LSMean weight (kg) and percentage contribution (%) to the cold carcass weight of six muscles (combined right and left sides) from blue wildebeest bulls (n=16) as influenced by production system and age. Significant differences ($p \leq 0.05$) are highlighted in bold.

Muscle		Production system		p-value	Age		p-value
		Extensive	Semi-extensive		Adult	Sub-adult	
Carcass weight	kg	84.9 ± 7.55	112.1 ± 6.38	0.003	111.3 ± 5.97	85.7 ± 8.24	0.005
LTL	kg	4.1 ± 0.43	5.6 ± 0.24	0.001	5.4 ± 0.30	4.2 ± 0.44	0.004
	%	4.8 ± 0.16	5.0 ± 0.11	0.308	4.9 ± 0.15	4.9 ± 0.14	0.911
BF	kg	4.1 ± 0.33	5.6 ± 0.23	0.0001	5.4 ± 0.22	4.3 ± 0.45	0.003
	%	4.8 ± 0.13	5.0 ± 0.11	0.209	4.8 ± 0.14	5.0 ± 0.09	0.318
SM	kg	3.1 ± 0.22	4.3 ± 0.18	<.0001	4.1 ± 0.22	3.3 ± 0.30	0.002
	%	3.8 ± 0.17	3.9 ± 0.14	0.588	3.7 ± 0.18	3.9 ± 0.11	0.439
ST	kg	1.3 ± 0.11	1.7 ± 0.10	0.012	1.6 ± 0.07	1.3 ± 0.15	0.029
	%	1.5 ± 0.04	1.5 ± 0.04	0.480	1.5 ± 0.05	1.5 ± 0.04	0.322
IS	kg	1.2 ± 0.11	1.5 ± 0.13	0.125	1.5 ± 0.09	1.2 ± 0.14	0.107
	%	1.4 ± 0.03	1.3 ± 0.06	0.073	1.3 ± 0.04	1.4 ± 0.06	0.295
SS	kg	1.0 ± 0.09	1.2 ± 0.10	0.057	1.2 ± 0.08	1.0 ± 0.10	0.055
	%	1.2 ± 0.05	1.1 ± 0.04	0.207	1.1 ± 0.04	1.2 ± 0.05	0.454
Total	kg	14.8 ± 1.22	19.8 ± 0.91	0.004	19.2 ± 0.85	15.4 ± 0.39	0.006
	%	17.5 ± 0.35	17.8 ± 0.31	0.515	17.4 ± 1.54	17.9 ± 0.22	0.287

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

3.4 DISCUSSION

This study sought to determine the meat production potential of extensively produced blue wildebeest bulls in comparison to semi-extensively produced bulls in South Africa. With little information on this found in literature, part of the present study aims to provide baseline data on the carcass characteristics and yields as influenced by two different production systems. This will provide a starting point for the meat industry to increase the utilisation of blue wildebeest meat as a key protein resource.

The undressed carcass weight was influenced by both production system and age. The mean undressed carcass weight from the semi-extensive systems was significantly higher (208.23 ± 11.14 kg) than those produced from the extensive system (168.79 ± 14.59 kg). This statistical difference in the average weights can be explained by the difference in diets and behaviour of the animals as influenced by the different production systems. Semi-extensively raised animals

receive strategic supplementary feed throughout the year to ensure optimum production. Thus they are maintained on a high nutritional diet where the feed is partially processed making it easier to digest and ingest (faster rate of feed throughput) (Ledger, 1963). They also exhibit minimal amount of movement as they are kept in 50 to 300 ha camps being in close proximity to feed and water resources (Herrera, Bermejo, Henríquez, Vallejo & Costa, 2011). All these factors cause the semi-extensive animals to have lower energy requirements than the extensive animals, where the extensive animals expend more energy to support increased body movements through walking and searching for food as well as increased feeding time due to the unprocessed physical nature of the feed consumed (Lachica & Aguilera, 2005; Herrera *et al.*, 2011). Another explanation could be that cows from the semi-extensive system are able to provide better maternal care due to the access to higher quality forage and supplementary feed during gestation as compared to cows from an extensive system (Pettorelli, Pelletier, Von Hardenberg, Festa-Bianchet & Cote, 2007). This will allow semi-extensive cows to produce milk of higher quantity resulting in the calves receiving higher nutrients in their greatest growth period after birth, growing faster than the extensive animals, resulting in them being heavier at similar ages (Herrera *et al.*, 2011). Similar results were recorded by Volpelli, Valusso, Morgante, Pittia & Piasentier (2003) where male fallow deer (*Dama dama*) that had received supplementary feeding had heavier undressed carcass weights than those that had grazed on natural vegetation. As expected, the weights of the animals also differed significantly between the age groups, adult and sub-adult. Adults being significantly ($p = 0.007$) heavier (211.2 ± 8.93 kg) than the sub-adult (165.9 ± 14.89 kg) blue wildebeest bulls. With the heavier undressed carcass weights the corresponding mean carcass weights for the semi-extensive (112.1 ± 6.38 kg) animals were heavier than the extensive animals (84.9 ± 7.55 kg).

The dressing percentage of an animal is an important principle considered when determining its meat production potential (Fitzhenry, 2016). In this study, semi-extensively produced blue wildebeest bulls had a significantly ($p < .0001$) higher dressing percentage ($53.8 \pm 0.49\%$) compared to the extensive blue wildebeest bulls ($50.2 \pm 0.34\%$). The weight of the stomach and intestines ante-mortem can influence the dressing percentage (Hoffman, Mostert, Kidd & Laubscher, 2009). A note of caution is however due here because the semi-extensive animals were fed the morning of the harvest and this could influence the dressing percentage to be lower than what it should be. The stomach and intestines (GIT) of the semi-extensive animals contributed 44.1% to the undressed carcass weight compared to 40.7% of the extensive animals.

The mean dressing percentage reported in this study compared favourably with the mean dressing percentage (51.6%) of blue wildebeest harvested in 2001 and 2003 at the Sandveld Nature Reserve (Van Schalkwyk, 2004), but was lower than the 54.9% obtained from blue wildebeest harvested during 1973 and 1974 at the Hluhluwe Game Reserve, KwaZulu Natal (Attwell, 1982). Higher dressing percentage obtained in the latter may be due to different dressing techniques used during slaughtering. When the dressing percentage is compared to other African antelope, it is

similar to black wildebeest (*Connochaetes gnou*) bulls (53.1%) (Hoffman, van Schalkwyk & Muller, 2009) and blesbok (*Damaliscus pygargus phillipsi*) (52.2%) (Hoffman, Smit & Muller, 2008), but lower than mountain reedbuck (*Redunca fulvorufula*) (54-56%) and kudu (*Tragelaphus strepsiceros*) (57.5%) (Hoffman *et al.*, 2009). The dressing percentage obtained for the sub-adults (51.5%) were also favourable in comparison to species highlighted above. This confirms that wild ungulates can complete with domestic livestock for meat production as they reach mature weight at a younger age (Skinner, 1984). When comparing the dressing percentage with domestic livestock, it can be compared to the dressing percentage of Nguni, Bonsmara and Angus that has been reported to be in the range of 50.3-53.8% (Muchenje, Dzama, Chimonyo, Raats & Strydom, 2008). However it's important to note that even though the dressing percentage is similar to that of cattle, the dressing percentage of the blue wildebeest is achieved with lower fat percentages (Ledger, 1963). For sheep breeds the dressing percentages that have been reported are much lower than those obtained in the current study, South African mutton merinos (41.5%) and dorrner sheep (44.2%), this is due to the skin with the wool of these sheep breeds contributing a high percentage to the undressed carcass weight (Cloete, Hoffman, Cloete & Fourie, 2004). Knowledge of the actual carcass weight is important in the industry as game meat is typically sold as price per carcass weight unit. Sometimes, the carcass weight could include the skin-on carcass weight as game carcasses are typically transported with skin on to minimise dehydration of the carcasses as few African game species have a subcutaneous fat layer. Therefore, in this scenario the skin weight (~15.5 kg; Table 3.3) would need to be added to the carcass weight and an adjusted price per weight unit calculated.

During the harvesting of game, edible by-products such as internal organs (liver, kidneys, lungs and heart) as well as external organs such as heads and feet are produced (McCrindle *et al.*, 2013). These products are normally undamaged during a commercial harvest as killing is done by trained marksmen that in order to ensure instant death, aim for head shots only. These products have formed part of the traditional diets of South Africans for centuries and therefore could be utilised as a low-cost protein source (Erasmus & Hoffman, 2017). In this study the semi-extensive animals produced higher weights for both external and internal organs. The large contribution of the head weight to the external offal weight can be attributed to the semi-extensive system having larger horns characteristics (Table 3.5) than the animals from the extensive production system. Nonetheless, the head still contains edible portions in terms of the tongue, cheeks and brains, unfortunately these weights were not determined and warrants further research. The larger weights of the other offal parts might indicate that the heavier the animal, with the semi-extensive system producing heavier animals in this study, the larger the offal parts are due to the different rates of development (Moneim, 2009). This was confirmed by the positive correlation (Pearson correlation matrix) between the undressed carcass weight and all the offal parts (Table 3.4). Therefore as expected due to better quality nutrition received by the semi-extensive animals more energy is available to be allocated to the growth and maintenance of tissues.

This reason may aid in explaining why a higher total muscle yield (of the six selected muscles) was associated with the semi-extensive animals (19.8 kg) in comparison to 14.8 kg in the extensively raised animals. The LTL and hindquarter muscles had a mean weight of 17.1 kg in the semi-extensive system compared to 12.6 kg from the extensive system animals. The hindquarter muscles are classified as having high growth impetus that grows more rapidly as the functional demands (e.g. weight increase) increases to provide maximum locomotion performance (Jones, 2014). These muscles are of economic importance as they are regarded as high value cuts (rump and silverside) in the meat industry because of its high lean meat to bone ratio as well as their better eating quality characteristics and therefore the semi-extensive animals will have a higher carcass value (Ledger, 1963; Keane & Allen, 1998). The IS and SS muscles are of less importance as they form part of the lower value shoulder muscles that are typically processed further into minced products. They are classified with average growth impetus, performing uniform functions throughout the life of the animal (Jones, 2014). This explains why there were no differences observed in the weight of these muscles between the different production systems as an increase in weight minimally causes an increase in the demand of these muscles. Interestingly however, there was no difference in the weight of these muscles between the two age groups. This was unexpected as in males there is an increase in the muscle weight of the shoulder and neck during puberty as they assist in survival and reproduction (Jones, 2014). There was no difference observed in the percentage contribution of the individual muscles weights nor the total yield of these muscles to the cold carcass weights, indicating that relative to their size, animals from both production systems and age groups deliver similar meat percentages.

There has been a tendency within the industry to castrate blue wildebeest bulls at weaning so as to minimise their aggression towards each other. During the data collection period, an opportunity presented itself to cull two castrated blue wildebeest bulls. As there were only two oxen, their data was not included in the present Chapter, however their data and a brief comparison with the data from the intact bulls is depicted in Addendum I.

3.5 CONCLUSION

The study has given reliable data on the meat production potential of blue wildebeest, clearly indicating that animals produced from a semi-extensive system exhibited had heavier carcasses and therefore has better meat production potential. This information is expected to be valuable for the meat industry in forecasting the economic viability of these animals derived from different production systems. It will also aid farmers who are thinking of producing game animals primarily for meat production. All the indications are that blue wildebeest bulls can provide a valuable protein and offal food source. While this study was able to give baseline data on the carcass yield of this species it was limited to only bulls. Therefore more research is required using a larger sample size on the effects of other extrinsic (age, season, intensive system, etc.) and intrinsic (sex) factors on the meat

production potential. Future studies should also include bone yields in order to determine bone contribution to dressing percentage and to calculate meat-to-bone ratios. Before the meat from this species can successfully enter the meat industry, studies on the effect of the different production systems on the meat quality parameters are essential.

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CHAPTER 4

PHYSICAL MEAT QUALITY ATTRIBUTES OF BLUE WILDEBEEST (*Connochaetes taurinus*) AS INFLUENCED BY PRODUCTION SYSTEM, AGE AND MUSCLE TYPE

ABSTRACT

This study quantified the physical quality of six muscles (*Longissimus thoracis et lumborum*, *Biceps femoris*, *Semimembranosus*, *Semitendinosus*, *Infraspinatus* and *Supraspinatus*) from eight blue wildebeest bulls from an extensive production system and eight from a semi-extensive production system (age balanced). Production system influenced muscle drip loss; higher values being associated with the semi-extensive system. Age influenced the drip loss, cooking loss, tenderness and lightness of the muscles; the sub-adult meat samples exhibiting the more desirable physical characteristics. Ultimate pH (pH_U), drip loss, cooking loss, tenderness and colour were influenced ($p \leq 0.05$) by muscle type. The mean pH_U values ranged from 5.6 - 5.8, with the forequarter muscles (IS and SS) having a higher pH_U ($p \leq 0.05$) compared to the other muscles. The drip loss values for the SM muscle ($1.9 \pm 0.22\%$) was significantly higher when compared to the other muscle types. The lowest drip loss values was associated with the IS muscle ($1.0 \pm 0.07\%$). Similarly, the lowest cooking loss was also associated with IS muscle and the highest for the ST and SM muscles. For tenderness, the highest Warner Bratzler shear force values was observed for the SM muscle (43.6 ± 1.44 N) and the lowest for the forequarter muscles (IS = 24.1 ± 1.16 N and SS = 24.4 ± 1.07 N). All muscles in this study delivered the meat colour measurements associated with game with L^* value <40 , high a^* and low b^* values. Differences in the physical meat quality attributes of blue wildebeest muscle were greater between muscles than between production system and age groups.

Keywords: Game meat, Blue wildebeest, pH, Drip loss, Cooking loss, Colour, Shear force.

4.1 INTRODUCTION

The game industry of South Africa has become a well-established and profitable industry (Kohn *et al.*, 2005). It makes up the sixth biggest agricultural sub-sector in this country, with an annual turnover of an estimated R7.7 billion since 2008 and covering more than 20 million ha of land (Otieno & Muchapondwa, 2016). The industry is expected to continue to increase in growth and economic value as farmers are continuously converting from conventional livestock farming to wildlife use (game farming), as livestock continues to fail in adapting to the increased weather variability and effects of climate change (Otieno & Muchapondwa, 2016). The utilisation of wildlife also offers an opportunity for conservation and better economic returns as it can be utilized in either a consumptive or non-consumptive manner, or both (Berry, 1986). Consumptively game species are utilised for trophy hunting, non-trophy recreational hunting and meat production (Barnes, 1998). The latter is increasing and becoming a regular activity due to the growth of the industry and the need to balance breeding and meat production to avoid limitations brought on by natural resources (vegetation) (Janvosky, 2016). Therefore there is an opportunity for expansion in the commercialisation of game meat.

The value of game meat production in South Africa was first recognised in the 1950's and was mainly focused on being exported to Europe (Carruthers, 2008). However, in the 1990's game meat was associated with the spread of foot-and-mouth disease, with trouble managing and maintaining the disease within disease zones, a ban was placed on exportation in 2011. In February 2014 the ban was lifted but game meat production and consumption still contributes only a small amount to the formal international and the local meat market, with only 8% being sold locally and none being exported due to compliance issues (Cloete, Van Der Merwe & Saayman, 2015; Taylor, Lindsey & Davies-Mostert, 2016). None the less, it is calculated that during the winter hunting season, up to 20% of the total fresh red meat consumed in South Africa is from hunted game (SAMIC, 2009).

Reasons for the lack of support from red meat consumers is that they are not always aware or have been ill-informed about the positive attributes linked to game meat (Hoffman, Muller, Schutte, Calitz & Crafford, 2005). They also tend to perceive game meat as being tough, dry and too dark in colour (Lawrie & Ledward, 2006). The latter possibly being caused by an overall low intramuscular fat (IMF) content found in game meat, a higher water holding capacity (WHC) or the incorrect cooking procedures used (Hoffman & Wiklund, 2006; Hocquette *et al.*, 2010). Therefore from a consumer's perspective the physical quality of meat is judged by visual attributes (colour, amount of visible water, amount of fat and textural appearance) and palatability attributes (tenderness and flavour) (Brewer, Zhu, Bidner, Meisinger & McKeith, 2001).

The ultimate pH (pH_u) that is measured 24 hours post-mortem is a direct consequence of muscle glycogen (energy) levels in the muscle at slaughter which affects shelf-life, colour, flavour,

tenderness and water-holding capacity (WHC) of the final meat product (Wiklund, Manley & Littlejohn, 2004). Since the type of forage consumed by the animal influences the level of glycogen in the muscle; forage/feed type could also inversely have an effect on the meat quality attributes (Lawrie & Ledward, 2006). Colour is a particularly important visual attribute as it is the first quality cue observed by consumers at the point of sale with acceptability being associated with the appearance of freshness (Mancini & Hunt, 2005; Troy & Kerry, 2010). Colour of the meat is influenced by the chemical status and quantity of the myoglobin in the meat (Lawrie & Ledward, 2006; Neethling *et al.*, 2017). The quantity of myoglobin is associated with muscular activity and high level of activity is related to more myoglobin in the muscle (Lawrie & Ledward, 2006). Tenderness is the most important eating quality (palatability) attribute sought after by the average consumer (Lawrie & Ledward, 2006; Webb & Erasmus, 2014). Tenderness of meat is influenced by the amount of IMF, the amount of connective tissue, the presence of muscle shortening and the enzymes associated with post-mortem tenderising (Swatland, 1994).

Consumers have also become more interested in animal origins showing that they are not only concerned about meat quality but also animal welfare thereby increasing the demand that animals should be raised under natural conditions which are free of disease, pollutants and medication (such as hormones, antibiotics and anti-parasitic drugs) are being voiced (Shack, Bergh & Du Toit, 2010). Game animals can be raised in a wide range of production systems from intensive, semi-extensive to extensive farms. However they are universally accepted as being organic due to limited use of chemical production enhancers (Hoffman & Wiklund, 2006). Most commonly, wildlife are farmed extensively where they roam freely and depend on natural vegetation for feed, shelter, etc. However, due to the success of the game industry, farmers have begun to intensify the production systems as is common for the production of beef and other domestic livestock. The aim of this strategy is to improve production efficiency by improving average daily gain and feed conversion rates (Hoffman & Cawthorn, 2013).

Blue wildebeest is a game species that can be found readily on any form of game farming system and it is widely distributed in South Africa with an annual population increase of 29 to 35% (Furstenburg, 2002). Numbers of this species has grown substantially with the breeding of colour variants; mainly the so called “Golden” wildebeest although there are also other groups such as the “crowned/kings” wildebeest. Frequently, during the breeding of these colour variants, hybrids as well as coloured animals (mainly bulls) that do not meet the breeding/stud selection criteria (normally due to inferior horns) are available for hunting or culling. This species is therefore seen as being ideal to address some of the game meat production demand. This means that this game species (particularly excess bulls) can play an important role in supplying meat to address the increasing local and global demand. It is well known that meat quality is affected by factors such as animal species, the forage consumed, the level of activity ante-mortem, muscle type and anatomical location (that, amongst others, are due to differences in muscle fibre characteristics) and the harvesting methods

(Vestergaard *et al.*, 2000). In order to improve quality, accurately inform consumers and make it competitive with other meat types it is important that all aspects of game meat quality be quantified (Kohn *et al.*, 2005). As mentioned, the blue wildebeest numbers are such that it is an ideal species for sustainable harvesting, yet little information exists on its meat quality and the factors that influence it. Therefore the aim of the study is to investigate the influence of production system and muscle type on the physical meat attributes of blue wildebeest bulls.

4.2 MATERIALS AND METHODS

4.2.1 Animals and study location

Eight animals were randomly culled from an extensive production system that grazed natural vegetation while roaming freely. Both bulls and cows roamed together. Eight animals were then selectively (according to age) culled from a semi-extensive production system. These animals were blue wildebeest splits which are individuals that carry the genes for the recessive colour. Animals ($n \sim 300$) were maintained in a breeding camp of approximately 600 ha, consisting of only bulls, and fed a daily ration of 3 kg/animal strategic supplementary feed. The formulation of the supplementary feed (mixed using a on-farm mixer to form a homogenous ration) at point of harvest was: grass (33.99%), maize (15.69%), Brewers grain (12.5%), molasses (12.55%), soya oil cake (7.32%), wheat (6.24%), cotton oil cake (5.23%), Lucerne (3.92%), lime (0.94%), phosphate trace-mineral supplement - high in monocalcium phosphate - (0.94%), mineral premix (0.34%), and salt (0.26%). This typical diet varies with regards to availability of the main ingredients. The two farms were approximately 45 km from each other.

The bulls from both systems were classed into either being reproductive (sexually mature) or sub-adults that have not yet reach reproductive maturity (Bothma *et al.*, 2010). Blue wildebeest bulls reach sexual maturity at about two years of age and therefore an adult bull was defined here to be older than 28 months (Estes, 1991).

Refer to the Materials and Methods of Chapter 3.2.1 for more details.

4.2.2 Culling and dressing

All animals were culled during the day using a 0.308 calibre rifle with a sound suppressor by a marksman on the back of a secure hunting vehicle. All animals were shot in the head, which is the requirement for game production that is destined for export, as this has been shown to be associated with the least damage and wastage of the carcass as well as avoiding contamination with intestinal, ruminal or blood content (Van Schalkwyk & Hoffman, 2016). After shooting, all animals were immediately exsanguinated. In the field, the time shot and details about the shooting were recorded. The animals were then loaded on the back of the culling vehicle and transported to the slaughtering facilities.

Upon arrival at the slaughtering facility, evisceration was done as according to Van Schalkwyk & Hoffman (2016) and the dressed carcass stored overnight in a cold room at 4°C.

4.2.3 Sample preparation

After ~24 hours of cooling, the following muscles were removed from both the left side of the carcass: forequarter muscles *infraspinatus* (IS) and *supraspinatus* (SS); hindquarter muscles *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST) were removed in their totality and the *longissimus thoracis et lumborum* (LTL) from between the last lumbar vertebra and the natural termination of the muscle at the cervical vertebra. Each muscle was weighed and the right cranial end was kept for physical analyses.

4.2.4 Physical analyses

For the physical analyses, three ~1.5 cm thick steaks were cut perpendicular to the longitudinal axis from the centre of the selected muscle.

4.2.4.1 Acidity (pH)

The ultimate pH (pH_u) was measured ~24 hours post mortem using a calibrated portable Crison pH25 meter with a glass electrode. The pH of each muscle was measured on the cranial end of the complete muscle once removed from the carcass and the electrode washed clean with distilled water between measurements.

4.2.4.2 Moisture loss

Moisture loss was measured to determine the water holding capacity of the meat using two procedures: drip loss from the raw meat and water loss from cooked meat as described by Honikel (1998).

Drip loss percentage was calculated after a steak was weighed to get an initial reference weight after which it was suspended in an inflated plastic bag, without touching the sides of the bag, at 4°C for 24 hours. After 24 hours the steak was removed and weighed after being blotted dry using absorbent paper to remove excess moisture. This moisture loss was expressed as a percentage of the initial mass of each portion.

Cooking loss percentage was measured by weighing the remaining steaks before placing the steak into a plastic bag that was subsequently submerged into a preheated water bath (maintained at 80°C) for 60 min and then cooled overnight at 4°C. Once cooled, the sample was removed from the plastic bag, blotted dry using absorbent paper to remove excess moisture and weighed. Cooking percentage was calculated by determining the difference between the raw mass and cooked mass and expressed as percentage of raw mass.

4.2.4.3 Warner Bratzler shear force (WBSF)

Subsequent to the cooking loss measurement, the cooled cooked samples were used to determine the tenderness of the meat. Six 1.27 cm diameter cylindrical cores (from the centre of the sample, care being taken to exclude any visible collagen tissue) were removed and sheared perpendicular to the fibres' longitudinal orientation with a Warner Brazler blade (circular cross section of 1.27 cm Φ), moving at a cross speed of 3.33 mm/s and fitted to an electrical scale to measure maximum weight (force), recorded in kg per 1.27cm Φ diameter. The average of the six readings was calculated and the value used to describe the tenderness of the particular muscle, with a greater force being associated with tougher meat (Honikel, 1998). The calculated average in kg per 1.27cm Φ diameter was then converted into newton (N) to maintain a consistent unit used throughout the thesis and for comparison with other reported values. Conversion was as follows:

$$\text{Shear force (N)} = \text{kg per 1.27 cm } \Phi * 9.81 / \text{Area}$$

$$\text{Where area} = \pi (1.27/2)^2$$

4.2.4.4 Surface colour

The colour of the fresh meat was determined on three ~1.5 cm thick steaks that were cut perpendicular to the longitudinal axis from the centre of the selected muscle and left to bloom for ~30 minutes. After the blooming period the colour coordinates were measured on five random locations on the surface of the cut meat using a Colour-guide 45°/0° colorimeter (BYK-Gardner GmbH, Gerestried, Germany), according to the CIE $L^*a^*b^*$ colour system (Honikel, 1998). This system reported coordinates measuring CIE L^* (lightness), CIE a^* (green-red value) and CIE b^* (blue-yellow value). Chroma value (saturation/colour intensity) and hue-angle (colour definition) was then calculated using the CIE a^* and CIE b^* values as follows:

$$\text{Chroma value (C}^*) = (a^{*2} + b^{*2})^{0.5}$$

$$\text{Hue-angle (}^\circ) = \tan^{-1}(b^*/a^*)$$

4.2.5 Statistical analyses

The experimental design was a completely random factorial with eight animals culled at random from each production system (extensive and semi-extensive; $n=16$) and two age groups (adult and sub-adult). The physical attributes (pH_u, colour, moisture loss and tenderness) were analysed by performing an univariate analysis of variance (ANOVA) using the General Linear Models (GLM) procedures of SAS software (Version 9.4; SAS Institute Inc., Cary, USA). The two main effects were production system (extensive and semi-extensive) and age (adults and sub-adults) with muscle (LTL, BF, ST, SS and IS) as the split plot factor.

A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). Where there was significant deviation from normality, such as when the standardised residual for an observation deviated with more than three standard deviations from the model value, these outliers were evaluated and where applicable, removed. To compare the means a Fisher's t-least significant difference was calculated (Ott, 1998). A 5% probability level was considered significant for all tests testing significance. The values are reported as the Least Square Means and standard error. Correlations were quantified by means of the Pearson's Correlation coefficient.

4.3 RESULTS

4.3.1 Acidity (pH)

No interaction ($p > 0.05$) was observed between the production systems, age groups and muscle types for the mean pH_U . There were also no differences between the different treatments; production system and age. Highly significant differences ($p < 0.0001$) were however observed in the pH_U between the different muscles types (Table 4.1). The pH_U was higher in the IS muscles (5.8 ± 0.03) and SS muscles (5.79 ± 0.03), with the lowest pH_U measured in the BF and LTL muscles.

4.3.2 Moisture loss

As pertaining to drip loss, there were interactions ($p = 0.011$) between muscle type and age group (Fig. 4.1). The highest drip loss being associated with the SM muscle of the sub-adult age group and the lowest with the IS muscle of both age groups. A higher drip loss for the adult age group was measured for the LTL and ST muscles compared to the sub-adult age group, while for the sub-adult age group the drip loss was higher in the BF, SM and SS muscles compared to the adult age group.

There were no interactions ($p > 0.05$) between the production systems and the different muscles types, however an interaction was observed between the two production systems and age groups ($p = 0.007$; Table 4.2). With a higher drip loss ($p \leq 0.05$) being measured for the semi-extensive sub-adult age group, while the other treatments did not differ from each other. Differences were observed between the production systems and between the two age groups. The semi-extensive system ($1.5 \pm 0.09\%$) was associated with a higher drip loss than the extensive production system ($1.3 \pm 0.07\%$) while a higher drip loss was seen in the sub-adults ($1.5 \pm 0.07\%$) than the adults ($1.3 \pm 0.10\%$).

A difference ($p < 0.0001$) was also observed for drip loss between the different muscle types (Table 4.1). The drip loss percentages for the SM muscles ($1.9 \pm 0.22\%$) were significantly higher when compared to the other muscle types. The lowest drip loss values was associated with the IS muscles ($1.0 \pm 0.07\%$).

There was no interaction between the treatments for the cooking loss ($p > 0.05$). However, a difference was observed for cooking loss between the two age groups ($p = 0.015$); with higher

cooking loss seen in the adult age group ($37.6 \pm 0.63\%$) compared to the sub-adult age group ($35.5 \pm 0.63\%$). There was also a difference ($p < 0.0001$) between the different muscle types (Table 4.1). The highest cooking loss being measured for the ST and SM muscles and the lowest for the IS muscle.

4.3.3 Warner Bratzler shear force (WBSF)

No interaction was observed for the shear force between the different treatments ($p > 0.05$). However, a difference was observed between the two age groups; with a higher mean shear force value being observed for the adult age group (35.7 ± 1.28 N) compared to the sub-adult age group (31.8 ± 1.34 N). There was also highly significant differences ($p < 0.0001$) for the shear force values between the different muscles (Table 4.1), the highest shear force value was observed for the SM muscle (5.6 ± 0.19 kg/1.27cm Φ ; 43.6 ± 1.44 N) and the lowest for the forequarter muscles; IS (3.1 ± 0.15 kg/ 1.27cm Φ ; 24.1 ± 1.16 N) and SS (3.1 ± 0.14 kg/1.27cm Φ ; 24.4 ± 1.07 N).

4.3.4 Surface colour

The colour of the fresh meat was measured ~24 hours post mortem after a blooming period of ~30 minutes. There was a significant interaction between age and muscle for the mean L^* values (Table 4.3). Higher L^* values were observed in the IS, LTL, SM, SS and ST of the sub-adult age group, with highest being recorded in the IS. For all the muscles, higher L^* values were observed in the sub-adult group when compared to the same muscle in the adult group.

There were significant interactions observed between production system and muscle type (production system \times muscle) for the mean a^* , Chroma values, and hue-angle, (as depicted in Figure 4.2). The a^* values (Figure 4.2a) were significantly higher for the forequarter muscles (IS and SS); with the highest being observed in the SS from the extensive system, followed by a slightly lower value for the IS, also from the extensive system. However, the latter did not differ significantly from the IS and SS from the semi-extensive production system. For the rest of the muscles, the opposite was seen with lower a^* values observed for the extensive system compared to the semi-extensive system for the same muscle; the lowest a^* values being observed for the SM, BF and ST from the extensive system. Similarly, the Chroma values (Figure 4.2b) were significantly higher for the forequarter (IS and SS) muscles from both production systems, whilst the lowest Chroma value was observed for the BF from the extensive production system. The hue-angles (Figure 4.2c) were found to be significantly higher in the ST and SM, with the highest being for the ST from the extensive system, whilst the lowest hue-angle was found in the forequarter (IS and SS) muscles from the extensive system. The hue-angles were higher for the LTL, BF and ST from the extensive system in comparison to the semi-extensive system, whilst the opposite was observed for the SM, IS and SS.

Table 4.1 LSMean (\pm standard errors) of the physical meat quality parameters measured in six selected blue wildebeest muscles.

Parameter	Muscle type						SEM	p-value
	LTL	BF	SM	ST	IS	SS		
pH _u	5.7 ^{bc} \pm 0.03	5.6 ^c \pm 0.02	5.7 ^b \pm 0.04	5.7 ^b \pm 0.02	5.8 ^a \pm 0.03	5.8 ^a \pm 0.03	0.02	<.0001
Drip loss (%)	1.6 ^{ab} \pm 0.15	1.4 ^{bc} \pm 0.15	1.9 ^a \pm 0.22	1.4 ^{bc} \pm 0.07	1.0 ^d \pm 0.07	1.2 ^{cd} \pm 0.06	0.17	<.0002
Cooking loss (%)	34.6 ^c \pm 0.85	37.2 ^b \pm 0.68	38.8 ^{ab} \pm 1.22	40.6 ^a \pm 0.43	30.8 ^d \pm 0.85	37.6 ^b \pm 0.59	0.75	<.0003
Shear force (Kg/1.27cm Φ)	4.9 ^b \pm 0.27	5.1 ^b \pm 0.19	5.6 ^a \pm 0.19	4.3 ^c \pm 0.13	3.1 ^d \pm 0.15	3.1 ^d \pm 0.14	0.15	<.0004
Shear force (N)	37.8 ^b \pm 2.07	39.5 ^b \pm 1.47	43.6 ^a \pm 1.44	33.3 ^c \pm 0.98	24.1 ^d \pm 1.16	24.4 ^d \pm 1.07	1.18	<.0005

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

^{a-d} Row means with different superscripts differ significantly at $p \leq 0.05$.

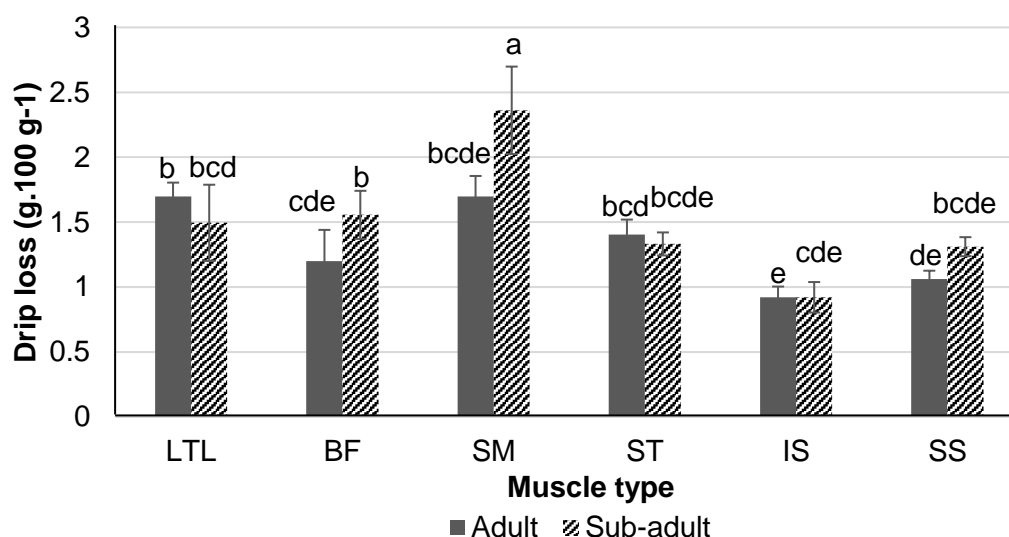


Figure 4.1 Interaction between age and muscle type ($p \leq 0.05$) for LS Mean drip loss of six blue wildebeest muscles. Means with different superscripts differ significantly at $p \leq 0.05$. LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

Table 4.2 Interaction between production system and age ($p \leq 0.01$) for the LS Mean drip loss percentage (\pm standard errors) of blue wildebeest.

Production system*age					p-value
Extensive adult	Extensive sub-adult	Semi-extensive adult	Semi-extensive sub-adult	SEM	
1.3 ^b \pm 0.10	1.3 ^b \pm 0.12	1.3 ^b \pm 0.09	1.8 ^a \pm 0.15	0.083	0.007

^{a-d} Row means with different superscripts differ significantly at $p \leq 0.05$.

The mean colour coordinate values of the blue wildebeest bulls' muscles are presented in Table 4.4. All the values of the variables CIE a^* , b^* , L^* , Chroma and hue-angles values differed ($p < 0.0001$) between the different muscle types. The forequarter muscles (IS and SS), hindquarter muscle (SM) and LTL had significantly higher L^* values when compared to the BF and ST hindquarter muscles. The forequarter muscles (IS and SS) also had significantly higher a^* values than the hindquarter (BF, SM and ST) and LTL muscles whilst the ST had the lowest a^* value. The b^* values were the highest in the SM and ST in comparison with the IS, SS and BF, whilst the lowest b^* values was measured in the LTL.

Table 4.3 LSMean CIE L* values (\pm standard errors) for six muscles from blue wildebeest bulls ($n=16$) depicting the interaction between age and muscles of blue wildebeest bulls.

Muscle type	Age		SEM	p-value
	Adult	Sub-adult		
LTL	32.8 ^{cd} \pm 3.36	34.7 ^{ab} \pm 3.33		
BF	30.4 ^g \pm 2.96	30.7 ^{fg} \pm 0.65		
SM	33.2 ^{cd} \pm 0.80	33.9 ^{bc} \pm 0.87	0.47	0.031
ST	30.8 ^{efg} \pm 0.94	33.0 ^{cd} \pm 0.81		
IS	32.0 ^{def} \pm 1.11	35.4 ^a \pm 0.92		
SS	32.1 ^{de} \pm 0.93	33.9 ^{bc} \pm 0.76		

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

^{a-f} Means with different superscripts differ significantly at $p \leq 0.05$.

A similar trend was seen for the Chroma values and hue values, with the IS and SS having significantly higher Chroma values compared to the other muscle types. The ST had the highest hue-angle, with the hindquarter muscles (BF, SM and ST) having higher values in comparison to the forequarter (IS and SS) and LTL muscles (Table 4.4).

There was a difference observed for the Chroma values between the different production systems, with higher Chroma values observed in the muscles from the semi-extensive production system (15.78 ± 0.21) compared to that from the extensive production system (14.89 ± 0.29).

Linear correlation coefficients between the ultimate pH and the physical parameters measured are presented in Table 4.5. An inverse relationship exists between pH and all the parameters except for the a^* and Chroma measurements. This indicates a general decrease in drip loss, cooking loss, tenderness, L^* , b^* and hue-angle with increasing pH_U of the meat.

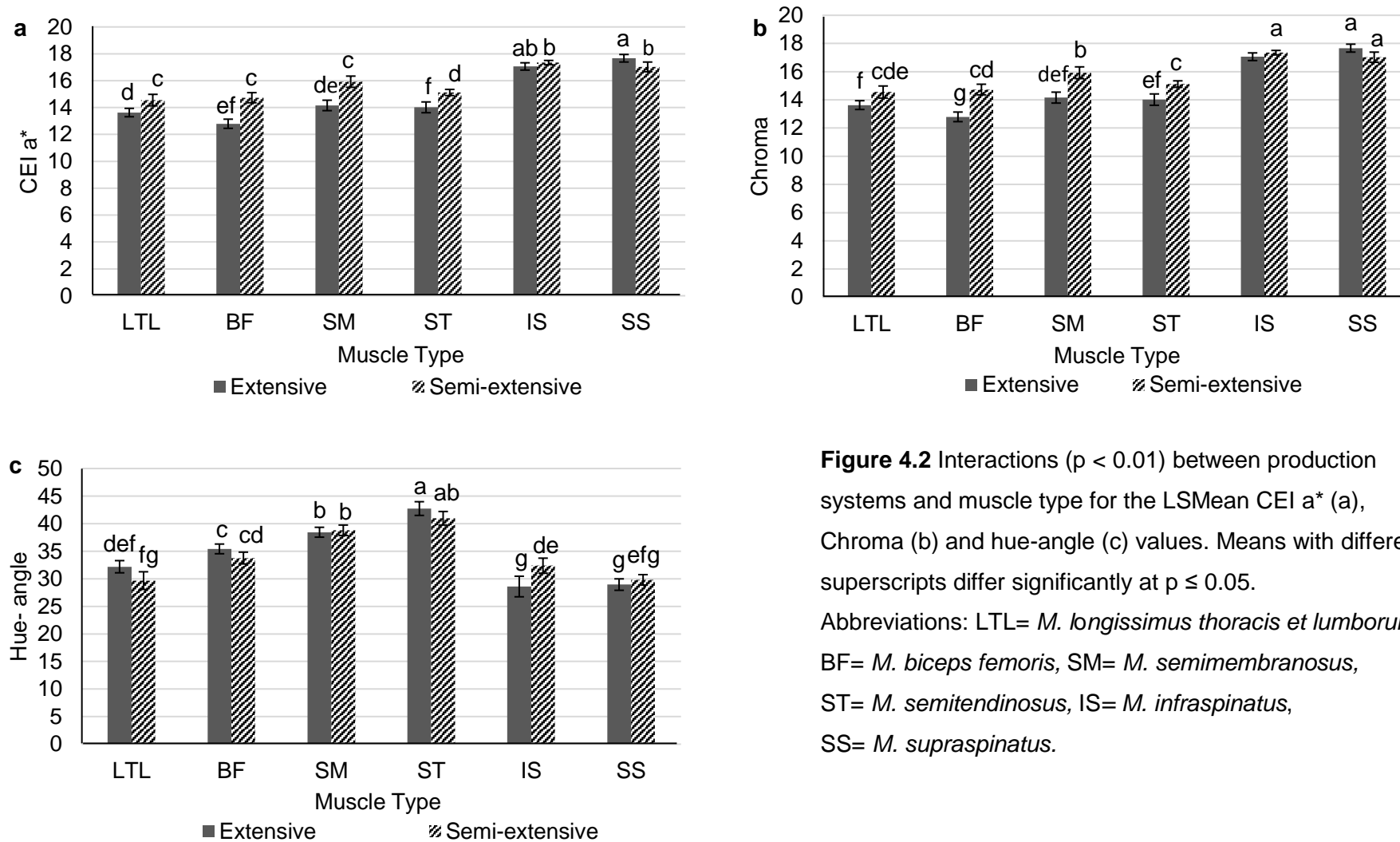


Figure 4.2 Interactions ($p < 0.01$) between production systems and muscle type for the LSMeans CEI a* (a), Chroma (b) and hue-angle (c) values. Means with different superscripts differ significantly at $p \leq 0.05$.

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

Table 4.4 LSMean (\pm standard errors) for the meat quality colour parameters of six selected blue wildebeest muscles, as influenced by muscle type.

Parameter	Muscle type						SEM	p-value
	LTL	BF	SM	ST	IS	SS		
L*	33.8 ^a \pm 0.70	30.6 ^c \pm 0.54	33.6 ^a \pm 0.58	31.9 ^b \pm 0.66	33.7 ^a \pm 0.83	33.0 ^a \pm 0.63	0.34	<.0001
a*	12.1 ^b \pm 0.25	11.3 ^c \pm 0.33	11.7 ^{bc} \pm 0.28	10.9 ^d \pm 0.29	14.8 ^a \pm 0.25	15.1 ^a \pm 0.25	0.17	<.0002
b*	7.3 ^d \pm 0.28	7.8 ^c \pm 0.21	9.4 ^a \pm 0.27	9.7 ^a \pm 0.19	8.7 ^b \pm 0.31	8.5 ^b \pm 0.19	0.19	<.0003
Chroma	14.1 ^{cd} \pm 0.28	13.8 ^d \pm 0.35	15.0 ^b \pm 0.36	14.6 ^{bc} \pm 0.27	17.2 ^a \pm 0.16	17.4 ^a \pm 0.24	0.18	<.0004
Hue-angle	30.9 ^d \pm 0.99	34.6 ^c \pm 0.70	38.6 ^b \pm 0.63	41.9 ^a \pm 0.87	30.5 ^d \pm 1.22	29.4 ^d \pm 0.69	0.65	<.0005

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

^{a-g} Row means with different superscripts differ significantly at $p \leq 0.05$.

Table 4.5 Pearson linear correlation coefficients and p-values between pH_U and the other physical measurements.

Parameters		Correlation matrix	
		r	p-value
Drip loss	%	-0.08	<i>ns</i>
Cooking loss	%	-0.39	<i>ns</i>
Shear force	kg	-0.33	*
Shear force	N	-0.33	*
L*		-0.11	<i>ns</i>
a*		0.29	*
b*		-0.10	<i>ns</i>
Chroma		0.23	**
Hue		-0.26	*

ns – no significant difference, *≤0.01, **<0.05

4.4 DISCUSSION

The aim of this study was to determine whether the production system in which blue wildebeest bulls are raised influences the physical meat quality attributes of the six selected muscles. The ultimate pH (pH_U) of all the selected muscles studied was not influenced by the different production systems or the age of the blue wildebeest bulls. However, there was variation in the pH_U between the different muscles, most probably caused by the difference in the main function and activity levels of each specific skeletal muscle. The function of a muscle determines the properties of the muscle which amongst others, can consist of different combinations of red or white muscle fibres and therefore the amount of glycogen stored (Kelly & Robertson, 2008). Glycogen directly influences the pH_U post-mortem by transforming into lactic acid through anaerobic glycolysis which decreases the pH_U of the muscle (Cassens & Cooper, 1971; Kohn *et al.*, 2005). A pH_U that is considered normal with no adverse effects on meat quality is 5.3-5.8 post-mortem (Honikel, 2004).

In the present study the pH_U measured in the different muscles ranged from 5.60 to 5.81 (Table 4.1), falling in the higher end of the ideal range. This was unexpected as the animals from both systems were culled at the end of the raining season and therefore should be in good condition as a consequence of a higher plane of nutrition, often associated with high levels of glycogen being present in the muscles ante-mortem and therefore a relatively low pH_U post-mortem (Cassens & Cooper, 1971; Kohn *et al.*, 2005). The higher than expected pH_U may be explained by the fact that the animals were culled during the day from the back of a vehicle and therefore the animals were more aware of disturbances causing short-term stress and higher physical effort (some of the animals were seen to move away from the vehicle prior to being culled) resulting in lower glycogen

levels in the muscles ante-mortem at the point of slaughter (Wiklund, Manley, Littlejohn & Stevenson-Barry, 2003; Kritzinger, Hoffman & Ferreira, 2003). Harvesting animals at night has been shown to be the most effective method of harvesting wild ungulates as it is the most humane and least stressful way (Kritzinger *et al.*, 2003; Hoffman & Laubscher, 2009). However, due to dense vegetation and rugged terrain in the extensive production system, implementing this method was difficult. Regardless of the possibility of stress during culling, the glycogen levels were still sufficient to ensure optimal pH_U of the meat. If the glycogen levels were too low post-mortem a pH higher than normal ($pH > 6.00$) would occur (Lawrie & Ledward, 2006).

This study reported a significantly higher pH_U in the forequarter muscles (IS and SS) (Table 4.1), indicating that these muscles had a lower glycogen level ante-mortem than the other muscles. The study took place at the start of the mating season (March to May) when the testosterone levels of bull's peak and therefore there is an increase in rutting activity. This is when bulls attempt to lure females for mating by showing dominance in the form of clashing with other bulls on bent knees and exchange horn thrusts, causing lower glycogen stores in the more active forequarter muscles. The ultimate pH of meat is important as it influences the physical properties of the final meat product produced; as it is closely correlated to the drip loss, cooking loss, tenderness and colour attributes (Węglarz, 2010; Table 4.5).

The total weight of muscles is made up primarily of water (75%; Huff-Lonergan & Lonergan, 2005). The ability of the muscle to retain this water post-mortem is known as water-holding capacity (WHC). This is important as the presence of fluid in the packaging of fresh meat, in addition to the colour, is considered by the consumer before purchase. High drip loss (large amount of fluid in package) is associated with a negative appearance and a decrease in consumer acceptability, therefore the meat industry strives at keeping the drip loss to the minimum (Troy & Kerry, 2010). There are several factors that affect WHC ante-mortem such as species, stress and harvesting methods, as well as post-slaughter processing such as chilling rate and aging (Kritzinger *et al.*, 2003; Lawson, 2004; Hoffman & Laubscher, 2009).

This study found significant interaction in the drip loss percentage between the different production systems and age groups (Table 4.2). A higher drip loss percentage was associated with the semi-extensive system sub-adult age group which may be attributed to the higher glycogen stores in these animals. A significant difference was also observed between the different muscles for the drip loss percentage (Table 4.1). The loss of water is attributed to the composition of the fibres within the muscles, the myofibrils and the spaces between filaments, which differ between different muscle types and are influenced by temperature and pre-slaughter stress (Honikel, 1998). The drip loss of the LTL was 1.6% which is lower than that found by Hoffman, Van Schalkwyk & Muller (2011), where the average drip loss percentage for the LTL muscle of blue wildebeest was 4.05%. The lower drip loss percentages of the current study can be explained by the influence of the pH_U which was above (Table 4.1) the isoelectric point ($pH_U \geq 5.4$ or 5.5) of meat. At this point proteins have a

negative charge which increases their ability to hold water and therefore results in a lower drip loss percentage (Huff-Lonergan & Lonergan, 2005). Contrasting to this, at a pH_U below the isoelectric point ($pH_U \leq 5.4$ or 5.5) there is an increase in protein denaturation causing the proteins to lose their ability to hold water and thus a greater drip loss percentage (Huff-Lonergan & Lonergan, 2005) as also seen in the study by Hoffman, Van Schalkwyk & Muller (2011). This general pattern was confirmed here where the highest pH (as mentioned previously) measured in the IS and SS was associated with the lowest drip loss. The SM and BF had the highest drip loss which was expected as these two muscles have higher surface area to volume ratios that would lead to increased drip loss. The lower drip loss percentage of the current study are similar to percentages that have been documented for sheep breeds (1.3 – 1.5%) (Ekiz *et al.*, 2009).

The WHC in this study was also determined by the amount of fluid exerted when cooked. During the cooking process, heating of meat causes changes in the physical and chemical properties of the proteins (Hamm & Deatherage, 1960). A lower cooking loss is associated with more meat fluid being retained and therefore enhanced juiciness in the final product, thus good quality meat is associated with less moisture loss than poor quality meat (Hamm & Deatherage, 1960; Sebsibe, 2008). There was no difference between the different production systems for cooking loss but there was for the age groups. A similar finding was reported by Volpelli, Valusso, Morgante, Pittia & Piasentier (2003), who reported no difference in cooking loss for the LM (*lumbar multifidus* muscle), located superficially to the spine, and SM muscles of fallow deer (*Dama dama*) fed different diets. The highest cooking loss was associated with the ST ($40.6 \pm 0.43\%$) and the lowest for the IS ($30.8 \pm 0.85\%$, Table 4.1), indicating that the latter muscle is possibly associated with juicier cuts. Similar results were reported by Fitzhenry (2016) while studying the meat quality of wild fallow deer in South Africa, where the highest cooking loss was observed for the ST (37.2%) and the lowest for the IS (28.5%) using the same procedures as described in Chapter 4.4.2. In this study the cooking loss for LTL was $34.6 \pm 0.85\%$, which is higher than reported for impala (31.0%) and kudu (31.5%) (Hoffman, Mostert, Kidd, & Laubscher, 2009), but lower than that of blue wildebeest bulls (39.42%) reported by Hoffman *et al.* (2011).

Meat tenderness is regarded as one of the most critical eating qualities that is sought after by the modern consumer (Erasmus & Webb, 2014). Meat from game animals is generally considered more tender than that of domestic livestock (Jansen van Rensburg, 2002). However, variations in tenderness do exist depending on many intrinsic and extrinsic factors of the animal and their interaction. These factors include muscle anatomical location, muscle fibre composition, amount of intramuscular fat, structure of the connective tissue and the presence of muscle shortening and enzymes associated with post-mortem tenderising, which all can cause variation in the pH_U and ultimately tenderness (Swatland, 1994; Lawrie & Ledward, 2006; Hoffman, Kroucamp & Manley, 2007; Destefanis, Brugiapaglia, Barge & Dal Molin, 2008; North, Frylinck & Hoffman, 2015).

Nutritional conditions of the animal can change the fibre type, glycogen level and solubility, muscular energy reserves and proteolytic activity which determines tenderness (Geay, Bauchart, Hocquette & Culioli, 2001). Therefore difference in muscle fibre characteristics influenced by feed ration, feed level and physical activity may influence the tenderness of meat (Vestergaard *et al.*, 2000). However, there was no difference in tenderness between the different production systems found in the present study. This was contrasting to previous studies that have shown that meat from animals farmed extensively tend to be tougher as the higher level of activity is associated with an increased muscle fibre concentration, less IMF, increased collagen and lower protein turnover due to slower growth rates (Nuernberg *et al.*, 2005; Resconi *et al.*, 2010; Frylinck *et al.*, 2013). However, because the animals were culled at the end of the raining season it can be postulated that animals from both systems were receiving a high plane of nutrition.

There was however a difference found in the tenderness of the muscles from the different age groups; the adult blue wildebeest bulls having a higher shear force value than the sub-adult animals, the latter therefore seen as being more tender. The increase in WBSF values in the muscles of the older blue wildebeest bulls might be due to the change in the development of the myofibrillar structure with age, as it has been shown that the Warner-Bratzler peak force represents the myofibrillar contribution to meat toughness (Shorthose, 1996). Another explanation could be that after puberty (then referred to as an adult) there is an increase in the testosterone in males that causes an increase in the amount of collagen and the number of thermo-resistant linkages between the collagen fibres in the muscle which reduces the tenderness of the muscle (Pommier, Fahmy, Poste & Butler, 1989).

There was also a significant difference in the tenderness of the different selected muscles (Table 4.1). Destefanis *et al.* (2008) found that in beef Warner Bratzler shear force values of < 42.8 N is an indication of tender meat while tough meat is indicated by a shear value > 52.68 N. In this study the Warner Bratzler shear force values were within the suggested tender range, with the exception of the SM exhibiting values just above 43.6 N. Thus the highest shear force values was seen in the SM and the lowest in the forequarter muscles (IS and SS), the latter therefore being considered most tender. Similar findings was found in blesbok (*Damaliscus pygargus phillipsi*) where the forequarter muscles were the most tender (Neethling, 2014). The selected blue wildebeest muscles can therefore be arranged from least to most tender as follows: SM, BF, LTL, ST, SS and IS. This result is contrasting to the notion that larger amounts of collagen (tougher meat) is found in heavily used muscles as those found in the distal thoracic limb (IS and SS muscles) than lightly used muscles found in the proximal pelvic limb (BF, SM and ST muscles). The size and anatomical location of the SM muscle can however be used to possibly explain the results of the present study. The size of the muscle allows for greater variability in the meat quality attributes, such as colour and tenderness of the muscle (Sawyer *et al.*, 2007). Therefore the larger blue wildebeest muscles (LTL, BF and SM) are associated with a great deal of variation in the fibre concentration which could

influence the WBSF values recorded depending on the tenderness gradient within an individual muscle. Therefore the location of sampling on a muscle could influence the results of the physical muscle profiling comparison, during this study all tenderness samples were taken from the caudal end of the muscle to maintain consistency. However, little research has been done on variability in the physical meat quality within blue wildebeest skeletal muscles, which could have influenced the tenderness readings.

An alternative explanation for the more tender forequarter muscles could be in the sampling procedures itself (as explained in 4.3.4.3), both these muscles are small with thick collagen layers however, the sampling procedure during the coring of the muscle for the determination of the shear force requires that no visible connective tissue be included in the core, this could therefore result in a sampling bias with the larger muscles having more, but thinner (and thus less visible) collagen. This theory warrants further research, possibly by analysing chemically the amount of collagen in the core samples.

When the mean shear force value of the LTL (4.9 ± 0.27 Kg/1.27cm Φ) reported in this study is compared to previous studies (kg/1.27cm Φ), it is higher than reported for springbok (*Antidorcas marsupialis*, 2.04 - 2.31; Hoffman *et al.*, 2007), impala (*Aepyceros melampus*, 3.21 - 4.08; Hoffman, 2000), black wildebeest (*Connochaetes gnou*, 3.23 - 4.28) blue wildebeest (3.77 - 4.60; Hoffman *et al.*, 2011) and mountain reedbuck (*Redunca fulvorufula*, 2.95 - 3.00; Hoffman, Van Schalkwyk & Muller, 2008). However comparisons with different studies can be complicated due to the lack of standardisation between different studies in sampling methods, sampling location on muscle and cooking techniques, although most of these referenced values were recorded using the same laboratory and techniques, a great deal of meat tenderness and thus shear force values is influenced by the pH_U and the decline in carcass temperature in the first 24 hours post mortem (Hoffman *et al.*, 2011).

With regards to the influence of pH_U on the tenderness of meat, it is known that the shear force values tend to increase with increasing pH_U and that optimal tenderness is achieved at a lower pH_U. However the opposite was reported in this study where the highest pH_U was observed in the forequarter muscles, which was also associated with the lowest shear force values. This could be as a result of significant variations in tenderness that have been suggested to become more apparent when meat has a pH_U > 5.75, as proteolytic activity decreases and consequently tenderisation (Devine *et al.*, 2006; Yu & Lee, 1986). In this study the pH_U values fell between 5.6-5.8, and therefore tenderness values of these muscles should be interpreted with caution. It has been shown that tenderness may increase at a pH_U > 6.3 due to the enhanced proteolytic enzyme activity that causes rapid tenderisation (Devine, Graafhuis, Muir & Chrystall, 1993). However meat with a pH > 6.0 is often associated with being dark-firm-dry (DFD) and a decrease in shelf life quality and since game animals, have an inherent “wildness” they are often more prone to this phenomenon (Hoffman *et al.*, 2009; Shange, Makasi, Gouws & Hoffman, 2018).

Colour is not an important eating quality but is the major factor that influences the initial selection of products for purchase by consumers (Geay *et al.*, 2001). Consumers want red and bright coloured meat, as this is associated with freshness, while pale or dark meat is unacceptable (Priolo *et al.*, 2001). Since the industry is no longer driven by production but rather consumer preference this parameter has become an important factor in the meat industry (Dransfield, 2003).

Stevenson-Barry, Duncan & Littlejohn (1999) and Neethling *et al.* (2017) reported that game meat has poor colour stability when compared to meat from domestic species. Game meat is also typically a darker red colour than meat from domestic species due to higher myoglobin content (Kritzinger *et al.*, 2003). This higher myoglobin content is because the muscles of free-roaming ungulates is often subjected to a greater activity load (Daszkiewicz *et al.*, 2012). The darker colour can also be due to low intramuscular fat or the indirect result of a higher pH obtained from pre-slaughter stress causing depleted glycogen reserves and as a consequence DFD meat (Wiklund, Manley & Littlejohn, 2004). Volpelli *et al.* (2003) reported that the dark colour associated with game meat that is attractive to consumers is characterised by an L^* value <40 , a high a^* and a low b^* value. All muscles in this study concurred with this. The mean LTL values for all the colour parameters obtained in this study were similar to those obtained for impala (Hoffman, 2000) and springbok (Hoffman *et al.*, 2007). In this study there were significant differences between the different muscle types reported for all the colour parameters measured.

A significant interaction for L^* value was noted between the two age groups (adult and sub-adult) and the different muscle types (Table 4.3). The sub-adult bulls produced lighter meat (higher L^* values) than the adult bulls for all the muscles. Similar finding was reported for springbok where adult males had a lower L^* value than the sub-adult age group (Hoffman *et al.*, 2007). The scattering of light is known to be influenced by the structure of the muscle and the extent of protein denaturation which changes with age as the muscle develops.

There was a significant difference in the lightness of the meat between the different muscles. With the forequarter (IS and SS), SM and LTL muscles having the higher L^* values, thus lighter than the BF and ST muscles. The inverse correlation between pH_U and L^* was low ($r = -0.110$), Table 4.5. This relationship (even though it was low) was expected as L^* measures luminosity (light scattering) which increases as the free water between the muscle fibres increases which occurs when pH is below or close to the isoelectric point ($pH_U < 5.4/5.5$). The correlation was low, most probably due to the low range of L^* and pH_U values used in calculating this relationship. The L^* values in this study were higher than found for impala or springbok (Hoffman, 2000; Hoffman *et al.*, 2007). Von La Chevallerie (1972) found that larger game species (such as blue wildebeest, ~272 kg) produced meat that is lighter and brighter than smaller game species such as impala (~53 – 76 kg) and springbok (~41 kg).

There was an interaction observed between the production systems and muscle types for a^* , chroma value and hue-angle (Fig. 4.2). The mean a^* values were higher in the forequarter muscles

(IS and SS) as well as the mean chroma values. Chroma is calculated using both a^* and b^* value, b^* had a moderate correlation with chroma value ($r = 0.397$, $p < 0.0001$), whereas a^* had a strong correlation with chroma values ($r = 0.916$, $p < 0.0001$). Therefore an increase in a^* values will have a greater contribution to an increase in chroma value in blue wildebeest muscles. Since the a^* value is generally positively correlated with the myoglobin concentration of meat and chroma with the saturation/intensity of the colour, the forequarter muscles of the blue wildebeest would have a more saturated red colour (Vestergaard *et al.*, 2000). This finding correlates with that found by Neethling, Suman, Sigge & Hoffman, (2016) where the IS steaks of blesbok demonstrated a higher redness, colour stability and Chroma than the LTL and BF muscles. This assumption however is supported by the knowledge that the SS muscle is classified as a 'red muscle' due to its high oxidative fibre content, low protein content and high connective tissue concentration (Lawrie & Ledward, 2006b). The ST had the lowest a^* values which is a muscle that is considered a more 'white muscle' due its high concentration of glycolytic Type BII muscle fibres (Vestergaard *et al.*, 2000). Skeletal muscles that are subjected to higher activity levels will contain higher concentrations of myoglobin and will therefore exhibit a darker, redder colour (Vestergaard *et al.*, 2000).

The b^* value was the highest in the SM and ST. This indicated that these muscles will have a more yellow/brown meat colour. This is because the b^* value is more associated with the myoglobin structure (higher amounts of metmyoglobin) and not the myoglobin concentration (Mancini & Hunt, 2005). Thus as expected, the forequarter muscles were associated with the lower b^* value. There was a negative correlation between a^* and the hue-angle value ($r = -0.706$, $p < 0.0001$), where a positive correlation was observed between the b^* and the hue-angle value ($r = 0.698$, $p < 0.0001$). Therefore consequently the meat samples with a higher hue-angle value will have a more yellow/brown colour, with the hindquarter (ST, SM and BF) muscles having the higher mean in this study. It has been suggested that consumers will only recognise the brown meat colour when about 60% of the myoglobin is oxidised to the metmyoglobin form (Lawrie & Ledward, 2006). Therefore the differences observed in this study with regards to the colour of the different muscles will most likely not be noticeable by red meat consumers.

4.5 CONCLUSION

This study aimed to quantify the physical quality of six main muscles from blue wildebeest bulls raised in different production systems. This will aid in the marketing and promotion of meat products derived from these animals. The results in this study show that the production system had a marginal influence on the physical meat quality with regards to drip loss with higher values being associated with the semi-extensive system, however, it is doubtful whether these differences will influence the consumers' perception of the meat. As expected, age influenced the drip loss, cooking loss, tenderness and lightness of the muscles. The sub-adult meat samples exhibited the more desirable characteristic in these physical parameters besides that of drip loss. However due to the small

sample size, the age factor should be interpreted with caution. In order to get a more reliable result, a larger sample size with larger age differences should be used; however it is always difficult to judge the age of wild ungulates when the period allowed to shoot is limited due to the inherent nature of wild animals. This study highlighted that the individual muscles influenced all the parameters measured (pH_U, drip loss, cooking loss, tenderness and colour). This information will be beneficial to the industry in deciding which muscles can be used for prime cuts and which can be used in further processing. The forequarter muscles were found to be more desirable with regards to drip loss, cooking loss, tenderness and intense red colour in comparison to the hindquarter muscles. However all the muscles were characterised by values that are generally associated with good quality by regular game meat consumers with differences being so slight that they might not be noticeable by these consumers. The game industry is continuously developing, resulting in a continuous change in the way game species are being farmed, often to a more intensified production system to optimise production. Further research on the effects of intensive production systems, for example where animals only consume supplementary feed, should be conducted. Another aspect that warrants further research is the quantification of the effect of sex, particularly that of older, mature animals on the physical meat quality parameters of these different muscles.

4.6 REFERENCES

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CHAPTER 5

PROXIMATE COMPOSITION OF BLUE WILDEBEEST (*Connochaetes taurinus*) MEAT AS INFLUENCED BY PRODUCTION SYSTEM AND MUSCLE TYPE

ABSTRACT

The objective of this study was to determine whether two contrasting production systems and six blue wildebeest muscles (*longissimus thoracis et lumborum*, *biceps femoris*, *semimembranosus*, *semitendinosus*, *infraspinatus* and *supraspinatus*) have an impact on the proximate composition (moisture, protein, intramuscular fat and ash) of the meat obtained from this species. Eight blue wildebeest bulls were obtained from an extensive production system and eight from a semi-extensive production system (age matched). Production system influenced the moisture, protein and ash content but not the intramuscular fat (IMF) content. Meat from the semi-extensive system had a higher ($p \leq 0.05$) protein and ash content, while the extensive system had a higher moisture content ($p \leq 0.05$). A significant difference in all the proximate chemical components was observed between the six muscle types. The proximate composition ranging from 75.9 - 78.5% moisture, 19.3 - 22.3% protein, 1.6 - 2.1% IMF and 0.99 - 1.1% ash content. The forequarter muscles were associated with the highest moisture and IMF and lowest protein contents. Although production system and muscle type differences in the proximate composition of blue wildebeest meat was statistically significant, the differences were numerically small and therefore it is debatable whether these differences are of biological value and relevance to human nutrition.

Keywords: Game meat, Blue Wildebeest, Meat quality, Proximate composition

5.1 INTRODUCTION

In Africa there is a continuous increase in the growth of the human population resulting in a shortfall in the supply of high quality proteins (Onyango, Izumimoto & Kutimaa, 1997). This is due to increasing population while livestock production has remained the same or declined due to various environmental challenges (DAFF, 2016). Meat and meat products are valuable sources of proteins, vitamins and minerals that play an important role in the human diet and therefore the search for new alternative meat sources has been intensified during the last few years (Hoffman, Mostert, Kidd & Laubscher, 2009). The exploitation of unconventional species such as game animals can be utilised as a means to increase meat production and consumption. In the dry and semi-arid regions of Africa where livestock production is limited, indigenous animals such as game species, are well adapted to a wide range of temperatures from low to high, efficiently utilising the natural vegetation and limited water supplies (Cole, 1990). These animals also have lower nutrient requirements, are generally more resistant to most diseases and parasites and have higher meat yields per unit area compared to traditional livestock (Von La Chevallerie & Van Zyl, 1971; Cole, 1990). Therefore producing meat from game animals requires low input systems while still being highly productive (Hoffman & Cawthorn, 2012).

Due to several factors supporting the farming of game species, the game industry in South Africa has grown and developed tremendously during the passed few years, with a 40-fold increase in the number of game species since 1960 being found on privately own land (Taylor, Lindsey & Davies-Mostert, 2016). In order to ensure continuous growth and sustainability of this industry it is important to exploit the game meat production opportunities presented by the game industry. Breeding animals in enclosures (irrespective of size) requires essential management principles such as regular culling to maintain an unspoilt habitat. Implementing this practice correctly can increase the availability of game meat on a larger and organised scale (Hoffman, Smit & Muller, 2008).

In addition to the need for protein to counter act the food security problem, red meat consumers have also become more health conscious and are actively looking for alternative protein sources that meets their nutritional demands. This is because the onset of heart disease and cancer have been linked to the consumption of unsaturated animal fat found in red meat (Radder & Le Roux, 2005). Therefore interest in the nutritional value and quality aspects such as wholesomeness, freshness, leanness and palatability of the meat before considering purchasing has increased (Dransfield, 2003; Radder & Le Roux, 2005; Hoffman & Wiklund, 2006).

The nutritional value and quality of meat is primarily defined by its basic chemical composition consisting of moisture, protein, intramuscular fat (IMF) and ash content, as it accounts for nearly 100% of the weight of animal tissue (Ang, Young & Wilson, 1984). Variations in these chemical constituents are mostly attributed to species, diet, maturity and different muscle anatomical locations within the carcass (Hocquette *et al.*, 2010). The latter causing the greatest variability in the

IMF content of meat (Hocquette *et al.*, 2010). Variation in intramuscular lipid concentrations caused by anatomical location is due to the differences in the composition of muscle fibre type, caused by differences in the physiological function and activity level of the muscle (Hocquette *et al.*, 2010; Astruc, 2014).

Studies on game meat have shown that the protein content varies between species but remains relatively high (>20%) (Hoffman *et al.*, 2009). Protein content of the common duiker (*Sylvicapria grimmia*) was reported by Hoffman & Ferreira, (2004) to be 25.7%, while Hoffman, Van Schalkwyk & Muller, (2009) reported that the protein content of springbok (*Antidorcas marsupialis*) ranged from 18.8 - 21.16% when obtained from different production systems. Thus several studies indicate that meat from African antelope species are healthy (Hoffman & Ferreira, 2004; Hoffman, Van Schalkwyk & Muller, 2009). However, regardless of this, game meat is still not readily consumed (Hoffman, Muller, Schutte, Calitz & Crafford, 2005). A possible reason for this is that red meat consumers are not always aware or have been ill-informed about the positive attributes linked to game meat due to limited nutritional information on specific game species in comparison to domestic meat species, with that available being restricted to the loin muscle, *longissimus thoracis et lumborum* (Hoffman *et al.*, 2005). This is therefore not a representation of the nutritional value of other marketable skeletal muscles of all game species.

In order to make quality control more feasible, specific muscles or groups of muscles are removed as individual muscles differ in biochemical composition and therefore eating quality (Lawrie & Ledward, 2006a). In order to accurately market game meat products based on their dietary benefits and to encourage its consumption both locally and internationally it is important to scientifically quantify the nutritional value of the different game species and the different muscles used for meat production (Jansen van Rensburg, 2002). It has become the norm in South Africa to market and export specific game muscles rather than traditional cuts that may contain more than one muscle.

Blue wildebeest (*Connochaetes taurinus*) is one of the larger antelope species found in South Africa that has become a popular addition to all types of game farming (Furstenburg, 2002). These animals are widely distributed in South Africa and have an annual population increase of 29 to 35% and therefore the demands for meat production can easily be met (Furstenburg, 2002). However before an animal can be considered for meat production it is essential that information on its nutritional composition be available, as this is important to encourage consumer purchase. However little scientific data exists on the nutritional/chemical value of South African game meat, with limited information on blue wildebeest (Hoffman *et al.*, 2009). The aim of this study was therefore to generate baseline data on the influence of different production systems (extensive vs semi-extensive) on the chemical composition (moisture, protein, IMF and ash contents) of blue wildebeest bulls' muscles. This will provide insight into whether blue wildebeest could be considered as a viable complementary or alternative source of animal protein.

5.2 MATERIALS AND METHODS

5.2.1 Animals and study location

A total of 16 blue wildebeest bulls (age 16 months to >4 years) were obtained from two different production farming systems situated in the Modimolle region in the Limpopo province, South Africa during March 2016. Eight animals were randomly culled from an extensive production system. These animals were free roaming and relied on the natural vegetation for consumption, receiving no additional feed. Eight animals were then selectively (according to age) culled from a semi-extensive production system. Within this system the animals received a balanced daily ration of 3 kg/animal strategic supplementary feed (that is mixed using a on farm mixer to form a homogenous ration). The animals consisting of only bulls ($n \sim 300$) maintained in a 600 ha camp. The bulls from both production systems were classed into two age groups (sub-adult and adult). Adult bulls were characterised as reproductive (sexually mature) while the sub-adult bulls were characterised as having not reached reproductive maturity. Blue wildebeest bulls reach sexual maturity at ~two years of age and therefore an adult bull in this study was defined to be older than 28 months (Estes, 1991). Refer to the material and methods of Chapter 3.2.1 for more detailed information.

5.2.2 Culling and dressing

The animals were culled/harvested during the day using a 0.308 calibre rifle with a sound suppressor by a marksman on the back of a secure hunting vehicle, with the aim to minimise the stress of the animals. All procedures performed during culling and slaughtering were done as according to Van Schalkwyk & Hoffman, (2016). The dressed carcass was then stored overnight at 4°C.

Refer to Material and Methods of Chapter 3.2.2 for more details.

5.2.3 Sample preparation

After ~24 hours of cooling, the carcasses were weighed and the shoulder muscles *infraspinatus* (IS) and *supraspinatus* (SS); hind limb muscles *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST) were removed in their totality while the loin muscle *longissimus thoracis et lumborum* (LTL) was removed from between the last lumbar vertebra and the natural termination of the muscle at the cervical vertebra. All muscles were removed from both the left and right side of the carcass and weighed and the right muscles caudal end was kept for chemical analyses and stored at $-2.6 \pm 0.07^\circ\text{C}$ until reaching Stellenbosch University laboratory where it was frozen at -20°C until analysis.

5.2.4 Chemical analyses

5.2.4.1 Sample preparation for chemical analyses

The samples were removed from -20°C and left to thaw overnight at 4°C prior to the homogenising process. Once defrosted the samples were trimmed to remove any excess fat or connective tissue, cut into smaller pieces and homogenised until paste like to ensure homogeneity. The sample was then allocated into appropriate chemical analysis bags, vacuumed to avoid moisture loss and oxidation and stored immediately at -20°C until analysis. These samples were then thawed overnight at 4°C before performing the selected chemical analyses.

5.2.4.2 Proximate analysis

Proximate analysis determines the nutritive content of the meat by quantifying the amount of moisture, protein, intramuscular fat (IMF) and ash content in all six muscles sampled from each of the animals. To determine the proximate content of each sample, duplicate analysis was done and average taken as the final measurement (if the two readings differed by more than 5%, additional analyses were performed).

The total lipid content (g/100 g) of a 5g muscle sample was analysed using a simple extraction with a solvent (1:2 (v/v) mixture of chloroform/methanol) as described by Lee, Trevino & Chaiyawat (1996). In this study the total lipid content extracted will be referred to as the intramuscular fat (IMF) content.

The defatted sample was dried at 60°C and used to analyse the crude protein content of the muscle sample. Crude protein was analysed using the LECO combustion method (also known as the Dumas Method) as described by AOAC International (2002b) official method 992.15. The dry and defatted sample was finely grinded and 1g encapsulated in Leco™ foil analysed in a Leco Nitrogen/Protein Analyser (Leco Fp-528, Leco Corporation). Between each batch of 15 samples, 1g calibration sample of EDTA (Leco Corporation, USA) was analysed to ensure the accuracy of analysis. Results were obtained in the form of nitrogen content (% N) of each sample. To determine the crude protein (g/100 g, the % N was multiplied by 6.25 (based on the assumption that proteins in meat contain approximately 16 percent nitrogen) and therefore 100/16 is 6.25

The moisture content (g/100 g) of each sample was determined according to the AOAC official method 934.0 (AOAC International, 2002c): 2.5g sample was dried at 100°C for 48 hours. The moisture free sample was then placed in a furnace of 500°C for a period of 6 hours to determine the ash percentage according to AOAC method 942.05 (AOAC International, 2002a).

5.2.5 Statistical analyses

This study consisted of a completely random factorial experimental design with two treatments (production system and age) and eight replications per treatment. The proximate analysis parameters (moisture, protein, IMF and ash) was statistically analysed by performing univariate

analysis of variance (ANOVA) using the General Linear Models (GLM) procedures of SAS software (Version 9.4; SAS Institute Inc., Cary, USA). The two main effects were production system (extensive and semi-extensive) and age (adults and sub-adults) and muscle (LTL, BF, ST, SS and IS) as the split plot factor.

The Shapiro-Wilk test was performed to test for non-normality of residuals (Shapiro & Wilk, 1965). In the event of significant non-normality ($p \leq 0.05$), outliers that deviated by more than three standard deviations from the model value were evaluated and where applicable, removed. To compare the means, a Fisher's t-least significant difference was calculated (Ott, 1998). A 5% probability level was considered significant for all tests testing significance. The values are reported as the Least Square Means and standard error.

5.3 RESULTS

No interaction ($p > 0.05$) was observed between the main effects (production systems, age and muscle type) for the different proximate analysis performed. Significant differences for the mean moisture, protein and ash content was observed between the different production systems (Table 5.1). Significantly higher moisture content was seen for the meat from the extensive production system ($77.5 \pm 0.19\%$) compared to the semi-extensive system ($76.5 \pm 0.17\%$), while higher protein ($p < 0.0001$) and ash ($p = 0.033$) percentages were associated with the meat from the semi-extensive system. There was no difference in the IMF content between the two production systems.

Table 5.2 depicts the significant differences in the proximate composition for the six blue wildebeest muscles. The SS had the highest mean moisture content that differed significantly from that of the LTL, BF, SM, ST and IS. The LTL and SM had the lowest moisture content but was associated with the highest protein content. Significantly, the lowest protein content was observed for the forequarter muscles, IS and SS. The IS had the highest IMF content, which differed from the mean IMF content of LTL, SM and ST. The BF had the highest mean ash content which differed significantly from the LTL and IS, but was similar to the other muscles.

Table 5.1 LSMean (\pm standard errors) for the proximate analysis parameters as influenced by production systems (g/100 g). Significant differences are highlighted in bold.

Parameter	Production system		p-value
	Extensive	Semi-extensive	
Moisture	77.5 ± 0.19	76.5 ± 0.17	0.0001
Protein	20.5 ± 0.23	21.6 ± 0.20	<.0001
IMF	1.8 ± 0.08	1.8 ± 0.08	0.792
Ash	1.01 ± 0.01	1.07 ± 0.01	0.033

Abbreviations: IMF= intramuscular fat

Table 5.2 Proximate analysis (g/100 g) of blue wildebeest muscles. Values indicated as LSMean (\pm standard errors).

Parameter	Muscle type						p-value
	LTL	BF	SM	ST	IS	SS	
Moisture	75.9 ^d \pm 0.25	76.5 ^{cd} \pm 0.26	76.0 ^d \pm 0.31	77.2 ^{bc} \pm 0.26	77.6 ^b \pm 0.20	78.5 ^a \pm 0.23	<.0001
Protein	22.3 ^a \pm 0.28	21.4 ^{bc} \pm 0.30	22.2 ^{ab} \pm 0.34	21.0 ^c \pm 0.26	20.0 ^d \pm 0.26	19.3 ^d \pm 0.29	<.0001
IMF	1.7 ^b \pm 0.13	1.8 ^{ab} \pm 0.12	1.6 ^b \pm 0.15	1.6 ^b \pm 0.12	2.1 ^a \pm 0.15	1.9 ^{ab} \pm 0.13	0.037
Ash	1.0 ^c \pm 0.02	1.1 ^a \pm 0.02	1.1 ^{ab} \pm 0.02	1.1 ^{ab} \pm 0.02	1.0 ^{bc} \pm 0.02	1.0 ^{abc} \pm 0.02	0.036

Abbreviations: IMF= intramuscular fat, LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*

^{a,d} Row means with different superscripts differ significantly at $p \leq 0.05$.

5.4 DISCUSSION

Mammalian muscle is considered a nutritionally valuable source of food as it is comprised of approximately 75% water, 19% protein, 2.5% intramuscular fat (IMF) and 3.5% soluble non-protein components such as carbohydrates, minerals and vitamins (Huff-Lonergan & Lonergan, 2005; Olsson & Pickova, 2005; Lawrie & Ledward, 2006a). This chemical composition can be altered by the production system in which the animals are raised due to the differences in management related to feed composition, feed intake and energy expenditure for maintenance (Olsson & Pickova, 2005). The composition of muscles also change with an increase in animal age because with age carcasses get heavier and the proportion of fat increases while the proportion of muscle and bone decreases (Warriss, 2000).

There was no difference in the proximate composition between adult and sub-adult blue wildebeest bulls of the present study. This is similar to that recorded by Hoffman, Mostert, Kidd & Laubscher (2009) for impala (*Aepyceros melampus*) and kudu (*Tragelaphus strepsiceros*) males where age/maturity did not influence the proximate composition of the meat. However a study on the chemical composition of springbok of different ages found that age had a significant effect on the moisture and IMF content of the LTL muscle (Hoffman, Kroucamp & Manley, 2007) although all indications are that in the springbok study the age differences were larger than that in this present study.

A close relationship between moisture content and the levels of IMF in mammalian muscles has been well established; when there is an increase in moisture content it is related to a decrease in the levels of IMF, and vice versa (Young, Frost, West & Braggins, 2001; Sebranek, 2014). This relationship has been confirmed by several studies. An inverse linear correlation was observed between moisture and IMF for springbok (Hoffman *et al.*, 2007), impala and kudu (Hoffman *et al.*, 2009), beef (Browning, Huffman, Egbert & Jungst, 1990) and lamb (Rowe, Macedo, Visentainer, Souza & Matsushita, 1999). However in contrast, this study noted a significant difference in the moisture content of the animals between the production systems while no difference in the IMF content was found. Even though a relationship between moisture and IMF was unclear in the results, a positive correlation ($r = 0.130$, $p = 0.207$) was noted, however not significant, and therefore it cannot be concluded that this finding is a true representation of the relationship between these chemical components in the meat of this species.

For moisture it was observed that animals culled from the extensive system had a higher value when compared to the semi-extensive system. A possible explanation for this could be the difference in the feeding regime between the production systems (Cheng & Sun, 2008). It has been noted that the ability of meat to retain water can be increased by lowering the digestible carbohydrates in the diet consumed by the animals (Cheng & Sun, 2008). Since the semi-extensively raised animals receive a supplementary diet that is partially processed, the digestibility of the feed

is increased, consequently decreasing the meat's ability to retain water. The supplement also contained higher energy from maize, brewery grains and molasses. While the muscles derived from the wildebeest raised in the extensive system had a higher moisture content, it was associated with a lower protein content. It has been found that when there is an increase in moisture content it is related to a decrease in the levels of protein. This is because charges in the various proteins molecules bind to water (when pH is above its iso-electric effect) however when these protein are denatured they lose their charge and decrease their binding to water, increasing the release of water from between the proteins causing an accumulation of moisture between the muscle fibres (Sebranek, 2014). Although there were statistically significant differences in moisture, protein and ash contents between production systems (Table 5.1), it is questionable whether these differences (~1%) are of biological value.

The differences in the composition of skeletal muscles is rather complex as it is influenced by several intrinsic factors including species, breed, gender, age, level of exercise, plane of nutrition and muscle anatomical location (Lawrie & Ledward, 2006b). The latter being the primary cause for chemical variation due to difference in physiological function, activity and growth. This causes differences in the composition of fibre types, IMF levels and connective tissue between muscles (Cassens & Cooper, 1971; Lawrie & Ledward, 2006b; Astruc, 2014). Therefore as expected, significant differences were found between the different muscle types for the all proximate components measured, with concentrations ranging from 75.9-78.5% for moisture, 19.3-22.3% for protein, 1.6-2.1% for IMF and 0.99-1.1% for the ash content (Table 5.2).

In terms of moisture, significantly higher values was found in the SS ($78.5 \pm 0.23\%$) compared to other muscles, while the SM ($76.0 \pm 0.31\%$) and LTL ($75.9 \pm 0.25\%$) had the lowest moisture content. Similar findings were found by Fitzhenry (2016) for wild fallow deer (*Dama dama*) in South Africa where the SS muscles was also recorded to have the highest moisture content and the SM and LTL muscles the lowest. The water content of meat products forms part of the essential meat quality parameters as it relates to the final yield and eating quality of the end product (Pearce, Rosenvold, Andersen & Hopkins, 2011). Results obtained in this studied are comparable to previous studies on blue wildebeest LTL muscles that ranged from 75.86 – 76.17% (Hoffman & Van Schalkwyk, 2011).

Protein was found to be highest in the LTL ($22.3 \pm 0.28\%$) and SM ($22.2 \pm 0.34\%$) while the lowest protein values were measured for the forequarter (IS: $20.0 \pm 0.26\%$; SS: $19.3 \pm 0.29\%$) muscles. This was expected as the LTL muscle has been shown to have a high protein concentration while the SS muscle has been classified with a low protein content (Swatland, 1994; Lawrie & Ledward, 2006b). The protein values of this study were found to exceed the protein value (19%) approximated for mammalian muscles, confirming that the protein content of game meat is higher than meat from domestic livestock (Jansen van Rensburg, 2002; Lawrie & Ledward, 2006a). The values obtained in this study were comparable to the protein values recorded previously for blue

wildebeest (22.73 - 23.43%, Hoffman & Van Schalkwyk, 2011) and other male African antelope species, namely for gemsbok (*Oryx gazella*, 20.3%, Onyango *et al.*, 1997), Blesbok (*Damaliscus pygargus phillipsi*, 22.18 – 22.45%, Hoffman, Smit & Muller, 2008), kudu (22.77 – 23.6%, Hoffman *et al.*, 2009) and black wildebeest (*Connochaetes gnou*, 20.45%, Hoffman, Van Schalkwyk & Muller, 2009).

A negative but low correlation was calculated between the pooled moisture and protein values of the blue wildebeest muscles ($r = -0.0940$, $p < 0.0001$), indicating the inverse relationship between these proximate components as mentioned earlier. The ratio of moisture to protein that is associated with meat is 3.6:1 to 3.8:1 (Sebranek, 2014). In the current study the ratio was found to be higher in the various muscles measured, ranging from 3.4:1 to 4.1:1. A possible explanation could be due to the high moisture values recorded in this study which are higher than have been recorded for other game and red meat types that varied between 70 and 75% (Hoffman *et al.*, 2007; Hoffman *et al.*, 2009; Sebranek, 2014).

Game meat is generally considered to contain < 3% IMF, however this chemical component is also considered the most variable due to muscle fibre composition differences between muscles within a species or across species related to function and activity levels (Hocquette *et al.*, 2010; Hoffman & Cawthorn, 2012; Sebranek, 2014). Fibre types are differentiated according to their metabolisms and expressed myosin heavy chain (MHC) isoforms, broadly characterised as red and white muscle fibres, that have been identified by observing their physiological responses to histochemical techniques (Cassens & Cooper, 1971, Swatland, 1994, Kohn *et al.*, 2005). However very limited information is available on the muscle fibre typing of different game species (Goldspink, 1996). Red muscle fibres (Type I), colour caused by high myoglobin content, are designed for oxidative metabolism (aerobic) being rich in oxidative enzymes (Cassens & Cooper, 1971; Kelly & Robertson, 2008; Lee *et al.*, 2010). These muscle fibres have low-ATPase activity and therefore are used in continuous motions that required slow-twitch contractions over long periods of time, thus suited for activities requiring strength and endurance (Swatland, 1994, Kelly & Robertson, 2008). This fibre type contains large amounts of mitochondria, low glycogen content and high fat content, the latter being the main fuel source for prolonged activities. Therefore as expected, a high fat value was obtained in the SS muscle which has been characterised as being a red muscle type (Lawrie & Ledward, 2006b).

On the other hand, white muscle fibres (Type IIB), colour caused by low myoglobin content, are designed for glycolytic metabolism (anaerobic) as they are rich in glycolytic enzymes (Cassens & Cooper, 1971, Kelly & Robertson, 2008, Lee *et al.*, 2010). These muscle fibres have a strong ATPase activity in order to perform fast rates of contractions (fast-twitch), thus best suited for fast rapid movements and therefore are characterised by higher glycogen and protein content than red muscle fibres but lower lipid contents (Lawrie & Ledward, 2006a). Therefore muscles that have

higher portions of white muscle fibre types are expected to have lower IMF levels, with the moisture and protein content fluctuating accordingly.

In this study the IMF content measured ranged from 1.6 - 2.1% within the different muscles studied, slightly higher than that obtained by Hoffman & Van Schalkwyk, (2011) (1.26 - 1.47%) for blue wildebeest males. The latter study being done only on the LTL muscle and from animals culled in the Free State region. Therefore the two studies were done in different regions with the animals thus being raised on different diets (different feed composition and feed intake) which has been shown to alter the chemical composition of meat (Olsson & Pickova, 2005). Therefore comparison to other studies is often rather complex and should be noted with caution due to the difference in animal nutrition. The results of this study are similar to IMF values that have been recorded in other African antelope species, namely kudu (1.48 - 1.58%, Mostert & Hoffman, 2007; Hoffman *et al.*, 2009), impala (2.06%, Hoffman *et al.*, 2009) and the common duiker (2.1%, Hoffman & Ferreira, 2004). When compared to domestic livestock, the fat content of pork is similar (2.1%, Kim *et al.*, 2008), however considerably lower than grain-fed beef (5.6%, Cordain *et al.*, 2002) and mutton (9%, Schönfeldt, Van Heerden, Sainsbury & Gibson, 2011).

The ash content which is an estimation of the salty and inorganic constituents, only slightly differed between the different muscle types (Table 5.2). In previously researched antelope species, the research tended to focus only on the LTL muscle making it difficult to draw muscle comparisons. Nonetheless, when the LTL's ash concentration ($0.99 \pm 0.02\%$) in this study is compared to previous studies, namely, blue wildebeest (0.23 - 1.32%, Hoffman & Van Schalkwyk, 2011), gemsbok (1.1%, Onyango *et al.*, 1997) and kudu (1.23%, Mostert & Hoffman, 2007), it was found to be comparable.

5.5 CONCLUSION

This study evaluated the proximate composition of meat from blue wildebeest bulls obtained from two different production systems (and therefore feed composition, feed intake and energy expenditure for maintenance). Although this study found that production system had an influence on moisture, protein and ash contents. The actual differences were small and a study with a larger sample size should be used to confirm the trends found in this study. Regardless of differences, it can be concluded that the meat from blue wildebeest is high in protein (~21g per 100g) and low in IMF (~1.7g per 100g) content. Thus it can be considered a valuable source of protein and from a health point of view, blue wildebeest meat can be regarded as lean and healthy. Nonetheless further research may be required to assess the effect of other intrinsic (sex) and extrinsic (season) factors on the chemical composition of this species' muscles. The results will aid in product labelling, consumer education and marketing of meat and meat products derived from this species. The results will also help in the further processing of meat from these animals as these chemical constituents can influence other quality parameter such as colour, flavour and juiciness which are all currently driving consumer-purchase activities.

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CHAPTER 6

SENSORY EVALUATION OF BLUE WILDEBEEST (*Connochaetes taurinus*) AS INFLUENCED BY PRODUCTION SYSTEM, AGE AND MUSCLE TYPE

ABSTRACT

Blue wildebeest are currently being produced in different combinations of production systems that differ in nutritional management and behavioural manipulation. Thus these animals receive variations in dietary composition and exercise which influence the fatty acid content and consequently the sensory quality of the meat produced. The aim of this study was to quantify the influence of production system (extensive vs semi-extensive), age (adult vs sub-adult) and muscle type (*Longissimus thoracis et lumborum* vs *biceps femoris*) on the sensory profile and fatty acid profile of blue wildebeest bulls. The sensory profile was determined by descriptive sensory analysis (DSA) in addition to various physical measurements (pH, thaw loss, cooking loss and Warner Bratzler shear force) and fatty acid profile to establish the sensory quality of blue wildebeest meat. The main effects had minor influences on the sensory profile with the meat being classified with an intense gamey, beef-like and sweet aroma and flavour. The former being attributed to a high concentration of polyunsaturated fatty acids (PUFA). The meat was associated with low tenderness (high shear force) which could be attributed to the cooking method or the high level of activity of these animals. The meat was associated with a relatively moderate initial juiciness and sustained juiciness attributed to the low cooking loss and thaw loss despite a very low intramuscular fat content of the meat. Differences in fatty acid profiles were attributed more to differences in production systems (differences in diets and activity) than age or anatomical location of muscles. Stearic acid (C18:0), linoleic acid (C18:2n6c) and α -linolenic acid (C18:3n3) contributed the highest percentage to the total fatty acids as well as producing a PUFA:SFA ratio and n6:n3 ratio within the recommended guidelines. The results provide an initial profile to assist on the marketing of meat products from this species.

Keywords: Game meat, Blue wildebeest, Descriptive sensory analysis, Aroma, Flavour, Fatty acids

6.1. INTRODUCTION

In South Africa the meat from game species has always been regarded as something unique with animals being primarily reared extensively in contrast to those farmed in America, Europe, Australia and New Zealand (Hoffman & Wiklund, 2006). However, with the growth of the game industry in South Africa, various combinations of production systems in which game species are reared have developed. Especially an increase in systems that implement a degree of feed supplementation in order to improve productive efficiency by increasing average daily gain and feed conversion rates (Hoffman & Cawthorn, 2013). This is mainly to produce animals of optimum quality for live sales or to allow breeding of animals in smaller camps making regular management interventions easier while still maintaining the integrity of the habitat (Oberem & Oberem, 2016).

Blue wildebeest (*Connochaetes taurinus*) is one of the larger game species that have become a popular addition to all forms of game farming from extensive to semi-extensive systems (Furstenburg, 2002). Therefore, these animals that are classified as bulk and roughage eaters, are being subjected to different diet regimes (feed composition, feed intake) and behavioural activities (energy expenditure for maintenance) as influenced by the different production systems (Estes, 1991). It is known that the composition of the diet consumed by animals influences the nutritional properties such as the fatty acid content of the meat and therefore as a consequence the sensory quality of the final product (Nuernberg *et al.*, 2005).

With consumers becoming more health conscious, so awareness and knowledge about dietary requirements have become important resulting in several organisations setting recommendations to ensure that products produced are maintained within consumer guidelines (Wood & Enser, 1997; Wood *et al.*, 2004). Meat is one of the main subjects with regards to diet as it is a major source of fat, especially saturated fatty acids (SFA), which have been linked to the onset of heart disease and cancer (MacRae, Reilly & Morgan, 2005; Radder & Le Roux, 2005). Therefore the World Health Organisation suggested a reduction in fat intake to between 15% and 30% of the total energy, with SFA's being reduced from 15% to 10% of energy intake while increasing the ratio of polyunsaturated (PUFA) to saturated fatty acids (P/S) to above 0.4 (WHO, 2003).

The reason for this is because SFA have been related to the development of high levels of cholesterol in the circulating lipoproteins where PUFA have the ability to modulate the risk factors associated with SFA's (Keys, Andersson & Grande, 1965; Eckel *et al.*, 2014). A low omega-6/omega-3 fatty acid ratio is desired because a high concentration of omega-6 PUFA's can have detrimental effects in inflammatory responses while omega-3 PUFA's has the ability to suppress these effects, potentially reducing chronic diseases (Simopoulos, 2001, 2002). Therefore a product is annotated with a good fat quality when it has a fatty acid profile with a high degree of PUFA's and an optimal ratio of omega-6 to omega 3 PUFA's (Olsson & Pickova, 2005). The latter being particularly low in ruminant meat due to ruminant diets containing large amounts of grass that contain high levels of linoleic acid (C18:2n6c), which is the most important omega-6 PUFA whereas α -linolenic acid

(C18:3n3) is the most important omega-3 PUFA (Wood *et al.*, 2004, Hoffman & Wiklund, 2006). Studies have also shown that game meat has substantially higher amounts of polyunsaturated fatty acids than domestic animals due to the differences in the diets consumed by the animals (Wiklund *et al.*, 2003; Hoffman, Van Schalkwyk & Muller, 2009). It is known that diets of ruminants influence the fatty acid profile to a lesser extent than monogastric animals, however there have been dietary effects reported for game species (Kohn *et al.*, 2005).

The fat content found in meat is affected by a number of factors including species, muscle type, sex and age (Hoffman, 2000). The relationship between fat composition and sensory characteristics have been observed in several studies performed on meat from domestic livestock, with fatty acids being shown to affect meat quality with regards to fat tissue firmness, shelf life and flavour (Wood *et al.*, 2004). It has also been suggested that the total amount of fatty acids found in meat can also influence tenderness and juiciness (Wood *et al.*, 2004). Therefore the dietary regime can influence the fatty acid profiles and ultimately the sensory quality of meat (Wiklund, Johansson & Malmfors, 2003; Neethling, Hoffman & Muller, 2016).

Sensory characteristics are the most important meat quality aspect of meat and meat properties (Bukala & Kedzior, 2001; Oltra *et al.*, 2015). With South African consumers indicating that taste and quality of meat is associated with juiciness, tenderness and flavour (Radder & Le Roux, 2005). Of these sensory attributes, tenderness is considered to be the most important factor influencing meat quality (Hoffman & Wiklund, 2006). Game species have characteristic differences when compared to domestic meat species but are evaluated using the same sensory criteria where a sensory panel identifies the sensory profiles of meat products and not the consumer preference or acceptance (Resurreccion, 2004; Neethling *et al.*, 2016). Game meat is associated with an acquired and unique taste and therefore aroma and flavour have specifically been defined for game species (Neethling *et al.*, 2016). Higher ratings for sensory attributes such as sweet-associated aroma and taste, beef-like aroma and flavour, juiciness and tenderness have been positively correlated to consumer preference of meat products (Oltra *et al.*, 2015). While higher ratings of sensory attributes such as gamey, metallic and liver aroma and flavour, manure-like aroma, sour taste, mealiness, residue and rubber or liver-like texture have been positively correlated to the dislike of meat products by consumers (Wiklund *et al.*, 2003).

In the deer industry practiced in New Zealand, a vast amount of research has been done to define the different production systems that give distinctive and high-value quality to venison (Wiklund *et al.*, 2003). However no research has been done on the effect of different production systems in South Africa on game meat and various meat quality attributes. The purpose of this study was therefore to investigate the effects of different production systems defined by different diet regimes and behavioural characteristics on the sensory characteristics and fatty acid profiles of blue wildebeest bulls. Correlations between sensory ratings and physical (pH, thaw loss, cooking loss and tenderness) and chemical (fatty acid profile) properties were also investigated.

6.2. MATERIALS AND METHODS

6.2.1. Animals and study location

A total of 16 blue wildebeest bulls (age 16 months to >4 years) were obtained from two different production farming systems situated in the Modimolle region in the Limpopo province, South Africa during March 2016. From an extensive production system where animals roam freely and rely on natural vegetation for consumption, receiving no additional feed, eight animals were randomly culled. Following this, eight animals were then selectively (according to age) culled from a semi-extensive production system to balance the age between the sampled animals. Within this system the animals received a balanced daily ration of 3 kg/animal strategic supplementary feed (mixed using a on farm mixer to form a homogenous ration) and kept in a 600 ha camp consisting of ~300 bulls. Adult bulls were characterised as reproductive (sexually mature) while the sub-adult bulls were characterised as having not reached reproductive maturity. Blue wildebeest bulls reach sexual maturity at ~two years of age and therefore an adult bull in this study was defined to be older than 28 months (Estes, 1991).

Refer to the material and methods of Chapter 3.2.1 for more detailed information.

6.2.2. Culling and dressing

The animals were culled during the day using a 0.308 calibre rifle with a sound suppressor by a marksman on the back of a secure hunting vehicle, with the aim to minimise the stress of the animals. All procedures performed during culling and slaughtering were done as according to Van Schalkwyk & Hoffman, (2016). The dressed carcass was then stored overnight at 4°C.

Refer to Material and Methods of Chapter 3.2.2 for more details.

6.2.3. Muscle sampling

After ~24 hours of cooling, the left *Longissimus thoracis et lumborum* (LTL) muscle was removed from between the last lumbar vertebra and the natural termination of the muscle at the cervical vertebra and the left *Biceps femoris* (BF) muscle was removed in its totality from the respective blue wildebeest carcasses. The individual muscles were weighed, all visible connective tissue removed, vacuumed packed and stored at $-2.6 \pm 0.07^{\circ}\text{C}$ until reaching Stellenbosch University laboratory where it was frozen at -20°C until the training and testing phases of the descriptive sensory analysis (DSA).

6.2.4. Physical analyses

6.2.4.1. Drip/Thaw loss

The drip/thaw loss was determined by weighing the left LTL and BF immediately after removal from each animal carcass before it was vacuum packed and stored. The same muscle was then allowed

to thaw for 36 hours at a temperature of 3 - 4°C to defrost, after which it was blotted dry and weighed. The drip loss was calculated as the difference in sample weight before and after defrosting, expressed as a percentage of the original weight of the meat sample.

6.2.4.2. *Acidity (pH)*

The ultimate pH (pH_U) was measured ~24 hours post mortem using a calibrated portable Crison pH25 meter with a glass electrode. The pH of each muscle was measured on the cranial end of the complete muscle once removed from the carcass and the electrode washed clean with distilled water between measurements. The pH was also measured after thawing, before DSA.

6.2.4.3. *Cooking loss*

The cooking loss was determined according to the method describe by AMSA (2015). After the sample had thawed it was blotted dry and weighed, the same was then repeated on the same sample after cooking. Cooking loss was then calculated as the difference in sample weight before and after cooking, expressed as a percentage of the initial sample weight.

6.2.4.4. *Warner Bratzler shear force (WBSF)*

The Warner Bratzler shear force test (WBSF) was used to analyse the instrumental shear force of the cooked LTL and BF meat samples (same samples as used for cooking loss determination) (Honikel, 1998). The readings of the cooked meat (wrapped in aluminium foil) was taken after 24 hours stored at 4°C. Six 1 cm³ cubes was cut parallel to the muscle fibre direction from the centre of the cooked meat samples. An Instron Universal Testing Machine (Instron UTM, Model 2519-107) attached with a Warner-Bratzler (WB) fitting, a 1 mm thick triangular (V-notch) blade with a semi-circular cutting edge (radius of 0.508 mm), was used (Voisey, 1976). The maximum WBSF values (N) required to shear a sample of cooked muscle perpendicular to the muscle fibre longitudinal axis (at a crosshead speed of 200 mm/min) was recorded for each sample.

6.2.5. **Sensory analysis**

6.2.5.1. *Sample preparation*

Sensory analysis was done on the four meat treatments (two production systems and two muscle types). The distribution of samples is presented in Table 6.1. The sensory analysis was done according to AMSA (2015). The muscles were thawed for 36 hours at 3 - 4°C after being stored at -20°C before the testing or training DSA was performed. Each sample (whole muscle) was placed in an oven bag along with a thermocouple probe inserted into the geometric centre of the meat sample on an open roasting pan. No salt (NaCl) or any other form of seasoning was added to the samples throughout the sensory analysis. The prepared samples was then placed into an oven (Hobart, France) preheated to 160°C and roasted until its internal temperature measured 75°C on the temperature logger (computerised electronic temperature control system) attached to the probe.

The cooked samples was left to cool for 30 min before weighing and blotted dry to measure cooking loss. After weighing, from the middle, samples were cut into 1cm x 1cm cubes keeping the size as consistent as possible. These cubes were then wrapped in aluminium foil and placed into glass ramekins that were coded with randomly selected three digit codes in order to ensure the serving sequence was randomised. The sample containing glass ramekins were preheated at 100°C for 10 min and evaluated within 10 minutes. The ramekins with the meat samples were placed in a preheated water bath set at 70°C near the panellists to ensure that each panellist evaluated the sample at a constant temperature. Distilled water (21 °C), salt-free water crackers (Carr, UK) and green apple quarters were served with the sample to cleanse and refresh the pallet before and between the tasting of the samples.

Table 6.1 Distribution of samples used to determine the effect of production system and muscle on the sensory attributes of blue wildebeest meat.

Muscle sample (Left)	Production system	
	Extensive (n)	Semi-extensive (n)
LTL	8	8
BF	8	8

Abbreviations: LTL = *Longissimus thoracis et lumborum*, BF = *biceps femoris*.

6.2.5.2. Descriptive sensory analysis (DSA)

The DSA was performed at the Department of Food Science (University of Stellenbosch) in the sensory laboratory. The DSA was used as a sensory technique to qualitatively describe the flavour, aroma and eating quality of blue wildebeest meat made up of the four treatments (two muscles x two production systems) with eight replications each. A panel consisting of thirteen meat sensory experienced judges was used to analyse the given samples. The panel underwent training for eight sessions, two per day, as according to AMSA (2015) and consensus method described by Lawless & Heymann, (2010). In each of these training sessions, each judge received three (1 cm³) cubes of 12 reference samples (Table 6.2) to provide a clear concept and understanding for a specific attribute associated with blue wildebeest and the other treatments.

After the training sessions the panel was able to develop and define descriptors resulting in the panel deciding on 22 aroma, flavour and texture attributes defined in Table 6.3. The Egyptian geese (*Alopochen aegyptiaca*) was obtained from the Mariendahl farm Elsenburg, Stellenbosch and the springbok (*Antidorcas marsupialis*) from Brakkekuil farm, Witsand. The rest of the products were all obtained from Woolworths Food supermarket. These sensory attributes were evaluated during eight testing sessions. The panel scored the samples by rating the intensity of each descriptor on a 100 point unstructured line scale, with 0 being annotated with “low intensity”, and 100 being annotated with “high intensity” (AMSA, 2015).

During the DSA the test re-test method was used. The panellists received the four treatments in a complete randomized order while being seated in individual tasting booths fitted with the software programme Compusense® five (Compusense, Guelph, Canada). The sensory analysis sessions took place in a room that was temperature-controlled (maintaining a constant 21 °C) and light-controlled (artificial daylight) (AMSA, 2015).

6.2.6. Chemical analyses

6.2.6.1. Intramuscular Fatty acids

The fatty acid (FA) profiles of the LTL and BF muscles from each of the blue wildebeest carcasses were determined independently. From each raw meat sample, 1 g was weighed out and the fat extracted (Folch, Lees, & Stanley, 1957), with a chloroform:methanol (2:1; v/v) solution containing 0.01% butylated hydroxytoluene (BHT) as an antioxidant. The samples were then homogenised for 30 seconds in the extraction solvent using a polytron mixer (WiggenHauser, D-500 Homogeniser). Heptadecanoic acid (C17:0) was used as an internal standard (catalogue number H3500, Sigma-Aldrich, Gauteng, South Africa) to enable the quantification of the individual fatty acids in each muscle sample. From the extracted fats a 250 µl sub-sample was taken and transmethylated for 2 hours at 70 °C using methanol: sulphuric acid (19:1; v/v) solution as the transmethylating agent. After the sample had been transmethylated it was left to cool to room temperature. Once cooled the resulting fatty acid methyl esters (FAME) were extracted with water and hexane. The top hexane phase was transferred to a spotting tube and dried under nitrogen once the distilled water and FAME-containing hexane fluids had separated. Fifty µl hexane was added to the dried sample of which 1 µl was injected into the gas chromatograph.

The FAMEs were analysed using a Thermo TRACE 1300 series gas-chromatograph (Thermo Electron Corporation, Milan, Italy) equipped with a flame-ionisation detector, using a 30 m TR-FRAME capillary column with an internal diameter of 0.25 mm and a 0.25 µm film (Cat. No. HY260M142P, Anatech, Cape Town, South Africa) and a run time of approximately 40 mins. The following oven temperatures were utilised: Initial temperature of 50 °C (maintained for 1 min) and a final temperature of 240 °C (attained after three ramps and maintained for a minimum of 2 mins). The hydrogen gas flow rate was set at 40 ml/min.

The FAME of each sample was identified by comparing the retention times with those of a standard FAME mixture (Supelco™ 37 Component FAME mix, Cat no. 47885-U, Supelo, USA), with results being expressed as either % or mg fatty acid/g meat.

6.2.7. Statistical analyses

The experimental design was a completely random factorial with 16 animals culled, eight from each production system (extensive and semi-extensive) and eight from each age group (adult and sub-adult). Descriptive sensory analysis data was pre-processed to test for panel reliability using a model

that includes panellist, replicate and sample effects and interactions (Naes, Brockhoff & Tomic, 2010). Following the confirmation of panel reliability, subsequent statistical analyses were conducted on means over panellists. Univariate analysis of variance was performed, according to the model for the experimental design, on all variables accessed (sensory, physical and fatty acids), using GLM (General Linear Models) Procedure of SAS software (Version 9.4; SAS Institute Inc, Cary, USA).

A Shapiro-Wilk test was performed on the standardized residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). In cases where there was significant deviation from normality outliers were removed when the standardized residual for an observation deviated with more than three standard deviations from the model value. Fisher's t-least significant difference was calculated at the 5% level to compare means (Ott, 1998).

In addition to the univariate ANOVAs, the data was also subjected to Multivariate methods such as Principal component analysis (PCA) and Discriminate Analysis (DA) (XLStat, Version 2016, Addinsoft, New York, USA) to visualise and elucidate the relationships between the samples and their attributes. Pearson correlation coefficients (r) were calculated to determine the significant correlations between specific variables where appropriate. A probability level of 5% was considered significant for the main effects, interactions and correlations. Values are reported as the LSMean \pm standard error.

Table 6.2 Reference standards used during the training for the descriptive sensory analysis (DSA) of blue wildebeest meat.

Reference	Description	Internal temperature	Scale
Egyptian geese ^a	Intense aroma and flavour associated with cooked game meat	75°C	0 = low intensity; 100 = high intensity
Springbuck ^b	Low aroma and flavour associated with cooked game meat	75°C	0 = low intensity; 100 = high intensity
Karoo lamb ^c	Aroma and flavour associated with cooked lamb meat with herby attributes	72°C	0 = low intensity; 100 = high intensity
Ostrich ^d	Metallic aroma and flavour associated with cooked game meat	72/75°C	0 = low intensity; 100 = high intensity
Liver ^e	Aroma, flavour and texture associated with cooked beef liver	No probe	0 = low intensity; 100 = high intensity
Beef shin	Texture associated with very tough meat	No probe	0 = extremely tough; 100= extremely tender
Beef fillet	Texture associated with very tender meat	72°C	0 = extremely tough; 100= extremely tender
Chicken ^f	Texture associated with very juicy meat	75°C	0 = low intensity; 100 = high intensity
Chicken overdone ^f	Texture associated with very dry meat (mealiness)	85°C	0 = low intensity; 100 = high intensity
Duck ^g	Aroma and flavour associated with fat (sweet, oily, buttery)	75°C	0 = low intensity; 100 = high intensity
Beef rump (grass fed) ^h	Aroma and flavour associated with roasted beef with herby attributes	72°C	0 = low intensity; 100 = high intensity
Overaged beef steak ⁱ	Aroma and flavour associated sour over-matured meat	72°C	0 = low intensity; 100 = high intensity

^aEgyptian goose (*Alopochen aegyptiaca*) breasts; ^bspringbok (*Antidorcas marsupialis*) *longissimus thoracis et lumborum* muscle; ^ckaroo lamb (*Ovis aries*) chops; ^dostrich (*Strutio camelus*) steaks; ^ebeef liver; ^fchicken (*Gallus gallus domesticus*) breasts; ^gduck (*Anas platyrhynchos*) breasts; ^hfree range beef steak and ⁱsteak aged for 32 days.

Table 6.3 Definition and scale of the sensory attributes tested during the descriptive sensory analysis.

Sensory attribute	Description	Scale
Aroma and flavour		
Overall meat ^a	The overall intensity of the meat aroma in the first few sniffs and flavour in first few tastings	0 =low intensity; 100 = high intensity
Gamey ^a	The overall intensity of the game meat aroma in the first few sniffs and flavour in first few tastings	0 =low intensity; 100 = high intensity
Beef-like ^a	The aroma and flavour associated with roasted beef in the first few sniffs and flavour in first few tastings	0 =low intensity; 100 = high intensity
Sweet, oily/buttery ^a	The aroma and flavour associated with a cream-like texture that hits the middle of your tongue almost like oil	0 =low intensity; 100 = high intensity
Metallic ^a	The impression of slightly oxidised metal, such as iron, copper in the first few sniffs and flavour in first few tastings	0 =low intensity; 100 = high intensity
Liver ^a	Aroma and flavour associated with cooked beef liver	0 =low intensity; 100 = high intensity
Barnyard ^a	The aroma and flavour described as earthy with animal scent that remind tasters of a barn	0 =low intensity; 100 = high intensity
Sour	Aroma and flavour associated with sour in the first few sniffs and flavour in first few tastings	0 =low intensity; 100 = high intensity
Salt flavour	Flavour associated with salt in first few tastings	0 =low intensity; 100 = high intensity

^aSensory attribute was tested for both aroma and flavour.

Table 6.3. *Continued.*

Sensory attribute	Description	Scale
Texture		
Mealiness texture	Disintegration of the muscle fibre into very small particle that are retained on the tongue within the first few chews	0 = extremely dry; 100 = extremely juicy
Initial juiciness	Amount of fluid exuded when pressed between the thumb and forefinger	0 = extremely dry; 100 = extremely juicy
Sustained juiciness	Level of juiciness perceived after first 5 chews using molar teeth	0 = extremely dry; 100 = extremely juicy
Tenderness	Impression of tenderness after the first 5 chews using molar teeth	0 = extremely tough; 100 = extremely tender
Residue	Residual tissue remaining in the mouth after first 10 chews	0 = none; 100 = abundant

6.3. RESULTS

6.3.1. Physical analyses

There was a significant interaction ($p = 0.020$) between the main effects (production system and age) for thaw loss (Figure 6.1). Significantly the highest thaw loss percentage was obtained in the samples obtained from extensive adult, semi-extensive adult and semi-extensive sub-adult blue wildebeest treatments, with extensive sub-adult category having the lowest thaw loss %.

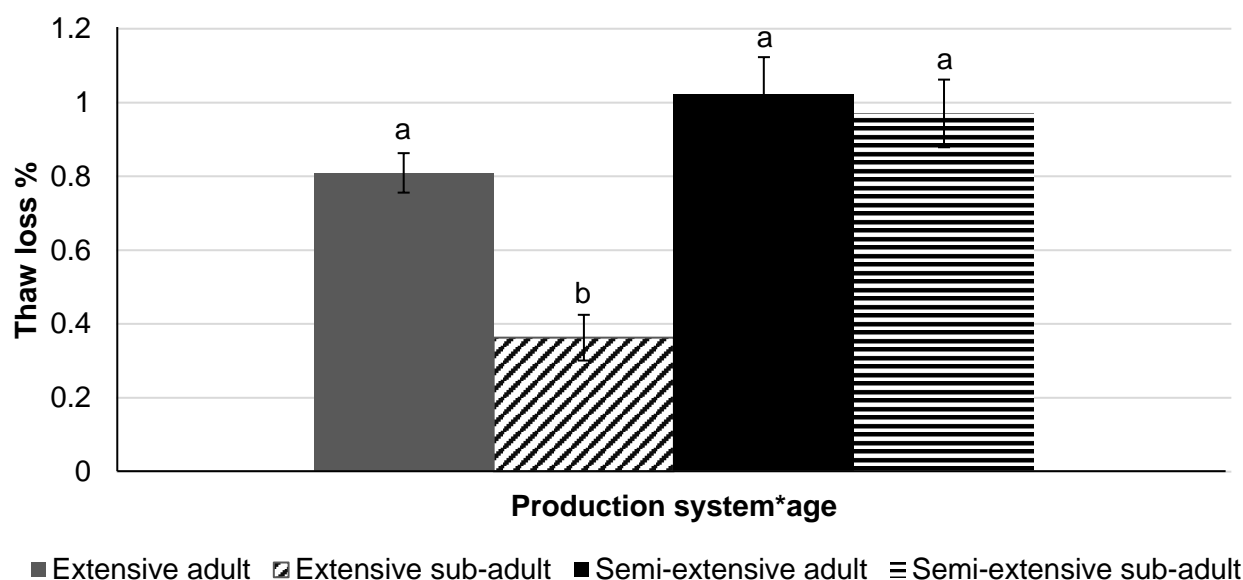


Figure 6.1 Interaction between production system and age for thaw loss (%). Means with different superscripts differ significantly at $p \leq 0.05$.

The mean values for the physical measurements of the main effects production system, age and muscle type is presented in Table 6.4. No significant interactions between the main effects were observed for the pH, cooking loss and WBSF values. No difference between the two muscle types were observed for any of the physical measurements. For the production systems and age category, there was a significant difference ($p \leq 0.05$) for thaw loss percentage. Meat from the semi-extensive system obtained a higher loss than the animals from the extensive system, while the meat from the adult blue wildebeest measured a higher loss in the same physical attributes than the sub-adult animals.

Table 6.4 The LSMeans (\pm standard error) of the physical measurements of blue wildebeest meat as affected by production system, age and muscle type. Means in bold differ significantly at $p \leq 0.05$.

Physical attributes		Production system		p-value	Age		p-value	Muscle type		p-value
		Extensive	Semi-extensive		Adult	Sub-adult		LTL	BF	
pH		5.7 \pm 0.05	5.6 \pm 0.03	0.434	5.6 \pm 0.02	5.7 \pm 0.02	0.375	5.7 \pm 0.04	5.7 \pm 0.04	0.990
Thaw loss	%	0.6 \pm 0.07	1.0 \pm 0.12	<.001	0.9 \pm 0.06	0.7 \pm 0.04	0.007	0.8 \pm 0.08	0.8 \pm 0.15	0.965
Cooking loss	%	34.0 \pm 0.03	34.1 \pm 0.03	0.946	34.9 \pm 0.03	33.2 \pm 0.04	0.374	32.2 \pm 0.04	34.9 \pm 0.02	0.403
WBSF	N	52.9 \pm 3.88	60.1 \pm 3.97	0.209	59.5 \pm 3.36	53.5 \pm 2.73	0.291	55.6 \pm 4.53	57.4 \pm 3.45	0.736

Abbreviations: LTL= *Longissimus thoracis et lumborum*, BF= *Biceps femoris*, WBSF = Warner Bratzler Shear Force.

^{a-b} Row LSMeans within main effects with different superscripts differ significantly at $p \leq 0.05$.

6.3.2. Sensory analysis

A significant interaction ($p=0.067$) existed between the main effects (production system, age and muscle) for the overall meat aroma and overall meat flavour of the blue wildebeest meat (Figures 6.2 and 6.3). The highest sensory rating for overall meat aroma was measured in the BF muscle from the semi-extensive sub adult category. Although it did not differ significantly from the ratings measured for the BF from the extensive and semi-extensive adult categories, it was significantly higher than the other treatments. Significantly, the lowest overall meat aroma rating was measured for the LTL from the extensive adult and sub-adult category. Similarly the lowest overall meat flavour rating was measured for the LTL from the extensive adult and sub-adult category, however it did not differ significantly from the LTL semi-extensive sub-adult, BF extensive sub-adult and BF semi-extensive adult categories. The highest sensory rating for the overall meat flavour was measured for the BF semi-extensive sub-adult category, which did not differ significantly from the BF extensive adult, BF semi-extensive adult and LTL semi-extensive adult categories.

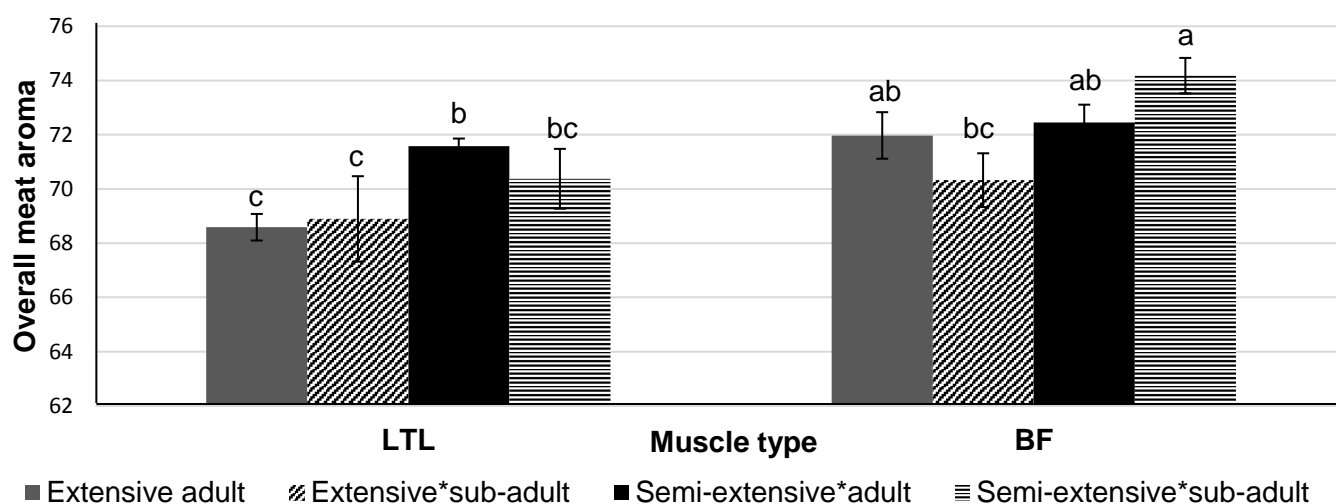


Figure 6.2 Interaction between production systems, age and muscle type for the overall meat aroma sensory attribute. LTL= *Longissimus thoracis et lumborum*, BF= *Biceps femoris*. Means with different superscripts differ significantly at $p \leq 0.05$.

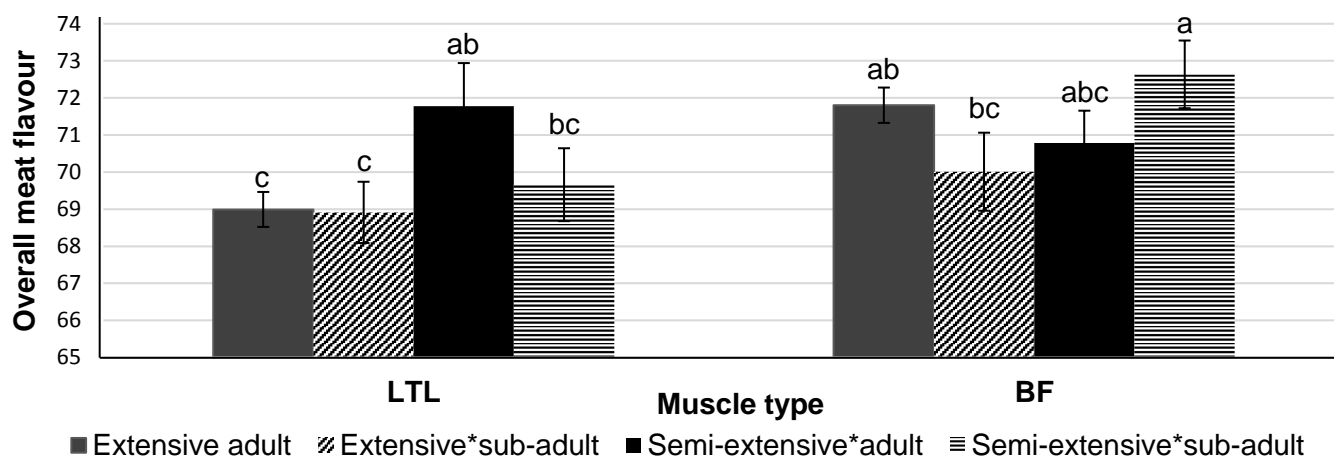


Figure 6.3 Interaction between production system, age and muscle type for the overall meat flavour sensory attribute. LTL= *Longissimus thoracis et lumborum*, BF= *Biceps femoris*. LSMeans with different superscripts differ significantly at $p \leq 0.05$.

The LSMeans (\pm standard error) of the sensory attribute rating are presented in Table 6.5. Liver aroma, liver flavour, sour aroma and sour flavour was not included as these sensory attributes each obtain zero ratings. No significant differences for the different sensory characteristics were observed between the two age treatments (adult and sub-adults). Production system influenced overall meat aroma ($p = 0.012$) and sweet oily aroma ($p = 0.029$). The mean overall meat aroma and sweet oily rating was significantly higher in the semi-extensive blue wildebeest meat than the contrasting production system. Overall meat aroma, overall meat flavour, mealiness, tenderness and residue sensory attributes differed significantly between the two blue wildebeest muscle types. Mealiness and tenderness mean ratings was highest in the meat derived from the LTL muscle type, while the opposite was seen for overall meat aroma, overall meat flavour and residue sensory ratings being higher in the BF muscle samples.

Overall the higher ratings were associated with the overall meat aroma, gamey aroma, beef-like aroma, overall meat flavour, gamey flavour and beef-like flavour sensory attributes.

6.3.3. Descriptive analysis

The descriptive analysis (DA) plot presented in Figure 6.4 classifies the differences between treatments (production system and muscle type). The DA plot describes 93.46% of the variation between treatments; with PC1 and PC2 describing 59.90% and 33.55% of the variation between treatments, respectively. Figure 6.4a illustrates the classification of the observations (production system and muscle type) and Figure 6.4b indicates all the variables used for the classification of the observations. According to the DA plot the semi-extensive LTL muscle is clearly separated from the other treatments on the far left of PC1 (Fig. 6.4a). The classification of the other treatments seem

less specific, however still different (Fig 6.4a), with the BF muscles of both production systems showing strong associations with the attributes on the right of PC1, and LTL of the extensive system on the left of PC1 (Figure 6.4b).

The descriptive analysis (DA) plot for the differences between the different production systems and muscles types for both sensory and physical attributes is presented in Figure 6.5. The DA plot describes 88.05% of the variation between treatments; with PC1 and PC2 describing 55.72% and 32.34% of the variation between treatments, respectively. According to the DA plot there is a less specific separation between treatments, with extensive BF, LTL and semi-extensive LTL appearing more to the left of PC1 (Fig. 6.5a). The semi-extensive BF muscle showing strong associations with the attributes on the right of PC1, Figure 6.6b.

6.3.4. Chemical analyses

6.3.4.1. Intramuscular Fatty acids

Table 6.6 presents the fatty acid profile (%) of blue wildebeest bulls as influenced by production system, age and muscle type. There was a significant ($p \leq 0.05$) difference between the production systems for saturated fatty acids C20:0 (Arachidic acid) and C24:0 (Lignoceric acid) with a higher % being associated with the semi-extensive production system. For all the treatments, C18:0 (Stearic acid), made up the highest percentage of the fatty acids measured, where after C18:2n6c (Linoleic acid) was the next fatty acid that obtained a high percentage relative to the other fatty acids measured.

A significant interaction ($p \leq 0.05$) existed between the main effects (production system and muscle type) for the total PUFA and n6 PUFA content of blue wildebeest meat (Fig. 6.6). Blue wildebeest BF derived from the semi-extensive production system had the highest PUFA and n6 PUFA content.

The IMF (intramuscular fat, g/100g) content of the blue wildebeest in this study was ~1.8 (Table 6.7) and therefore the fatty acids were present in very low levels (<10 mg/g of meat), with the exception of C18:0 (Stearic acid). The SFA's contributed the most to the total fatty acids in the meat, followed by the total PUFA and n6 PUFA fatty acids (Table 6.7). The lowest contribution was from the total MUFA and n3 PUFA fatty acids.

Table 6.5 The LSMean sensory ratings (\pm standard error) of blue wildebeest meat as affected by production system, age and muscle type. Means highlighted in bold differ significantly at $p \leq 0.05$.

Sensory characteristic	Production system		Age		Muscle type	
	Extensive	Semi-extensive	Adult	Sub-adult	LTL	BF
Overall meat aroma	69.9^b \pm 0.58	72.1^a \pm 0.49	71.1 \pm 0.48	70.9 \pm 0.72	69.9^b \pm 0.54	72.2^a \pm 0.51
Gamey aroma	66.6 \pm 0.69	67.0 \pm 0.71	66.6 \pm 0.72	66.9 \pm 0.67	67.2 \pm 0.59	66.3 \pm 0.78
Beef-like aroma	61.7 \pm 0.92	63.9 \pm 0.93	62.8 \pm 0.97	62.8 \pm 0.95	61.9 \pm 0.80	63.7 \pm 1.05
Sweet oily aroma	13.2^b \pm 0.34	14.2^a \pm 0.26	13.7 \pm 0.33	13.7 \pm 0.32	13.3 \pm 0.26	14.0 \pm 0.37
Metallic aroma	12.4 \pm 0.39	12.0 \pm 0.39	12.2 \pm 0.42	12.2 \pm 0.37	11.7 \pm 0.35	12.7 \pm 0.39
Barnyard aroma	0.5 \pm 0.17	0.5 \pm 0.17	0.5 \pm 0.16	0.6 \pm 0.18	0.4 \pm 0.13	0.7 \pm 0.19
Overall meat flavour	69.9 \pm 0.45	71.2 \pm 0.53	70.8 \pm 0.46	70.3 \pm 0.56	69.8^b \pm 0.50	71.3^a \pm 0.46
Gamey flavour	63.4 \pm 0.73	63.4 \pm 0.52	63.6 \pm 0.67	63.2 \pm 0.60	63.0 \pm 0.57	63.8 \pm 0.68
Beef-like flavour	62.2 \pm 0.63	63.7 \pm 0.71	62.8 \pm 0.66	63.1 \pm 0.73	62.5 \pm 0.60	63.4 \pm 0.77
Sweet oily flavour	14.0 \pm 0.26	14.1 \pm 0.34	13.8 \pm 0.27	14.3 \pm 0.32	13.9 \pm 0.27	14.2 \pm 0.32
Metallic flavour	14.7 \pm 0.64	14.8 \pm 0.73	14.7 \pm 0.67	14.9 \pm 0.71	14.2 \pm 0.51	15.4 \pm 0.80
Barnyard flavour	0.2 \pm 0.17	0.2 \pm 0.17	0.1 \pm 0.16	0.2 \pm 0.18	0.1 \pm 0.13	0.2 \pm 0.19
Salty	10.0 \pm 0.01	10.0 \pm 0.01	10.0 \pm 0.01	10.0 \pm 0.01	10.0 \pm 0.01	10.0 \pm 0.01
Mealiness	15.6 \pm 1.09	14.5 \pm 1.10	15.8 \pm 1.26	14.3 \pm 0.88	17.0^a \pm 1.21	13.1^b \pm 1.69
Initial juiciness	44.2 \pm 2.87	41.2 \pm 2.05	42.1 \pm 2.80	43.2 \pm 2.21	42.0 \pm 2.49	43.4 \pm 2.54
Sustained juiciness	36.3 \pm 1.47	35.0 \pm 1.35	34.4 \pm 1.53	36.8 \pm 1.24	35.6 \pm 1.54	35.7 \pm 1.30
Tenderness	48.0 \pm 2.36	45.6 \pm 2.10	45.4 \pm 2.54	48.3 \pm 1.86	51.0^a \pm 2.09	42.6^b \pm 1.86
Residue	34.1 \pm 1.67	34.1 \pm 1.81	34.2 \pm 1.99	34.0 \pm 1.45	30.0^b \pm 1.49	38.2^a \pm 1.27

Abbreviations: LTL= *Longissimus thoracis et lumborum*, BF= *Biceps femoris*.

^{a,b} Row LSMeans within the main effects with different superscripts differ significantly at $p \leq 0.05$.

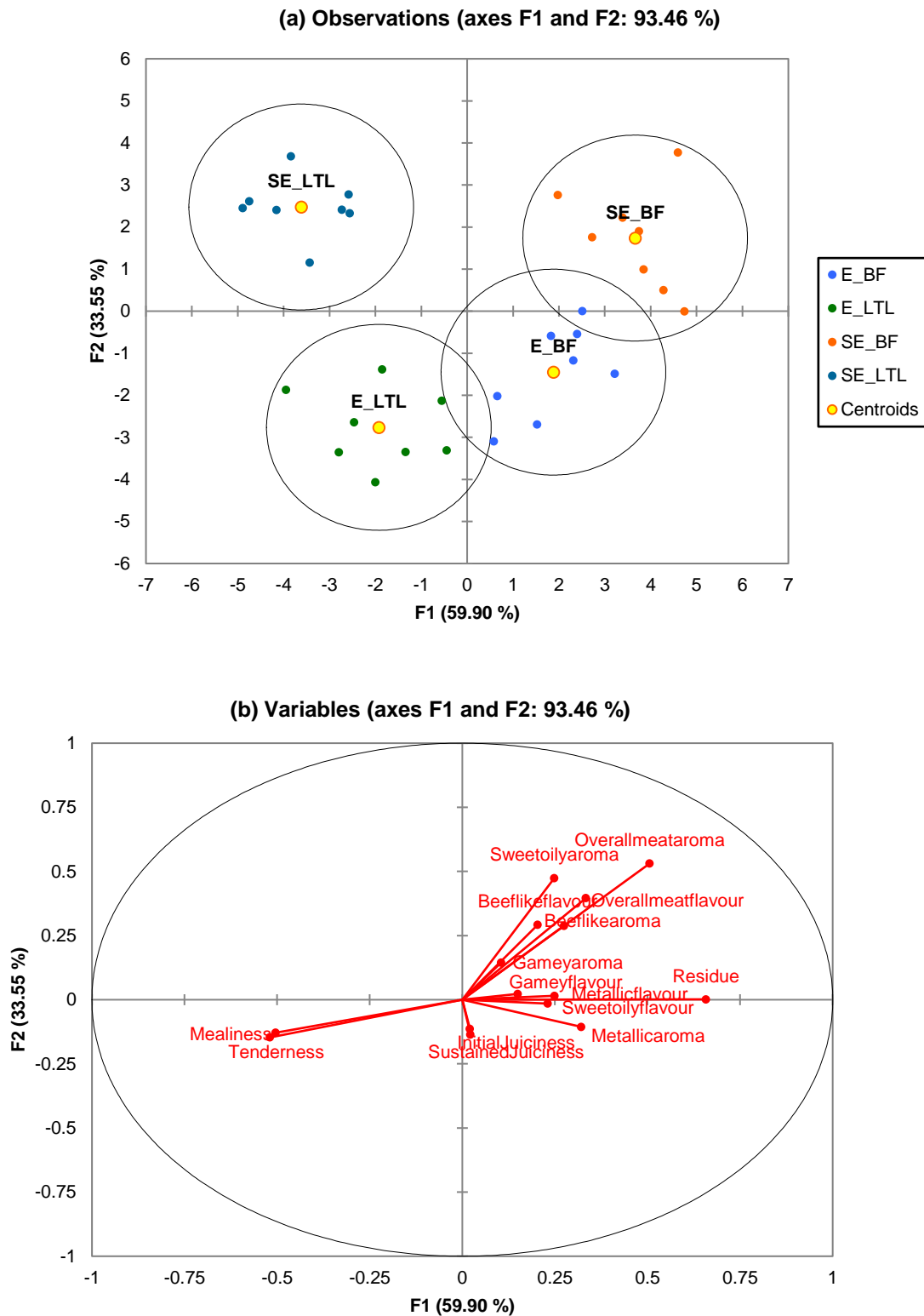


Figure 6.4 DA plot of the (a) mean observations for production system and muscle type for the sensory variables (SE_LTL, semi-extensive *Longissimus thoracis et lumborum*; SE_BF, semi-extensive *Biceps femoris*; E_LTL, extensive *Longissimus thoracis et lumborum*; E_BF, extensive *Biceps femoris*), with regard to all the sensory variables (b) used for the classification of the observations.

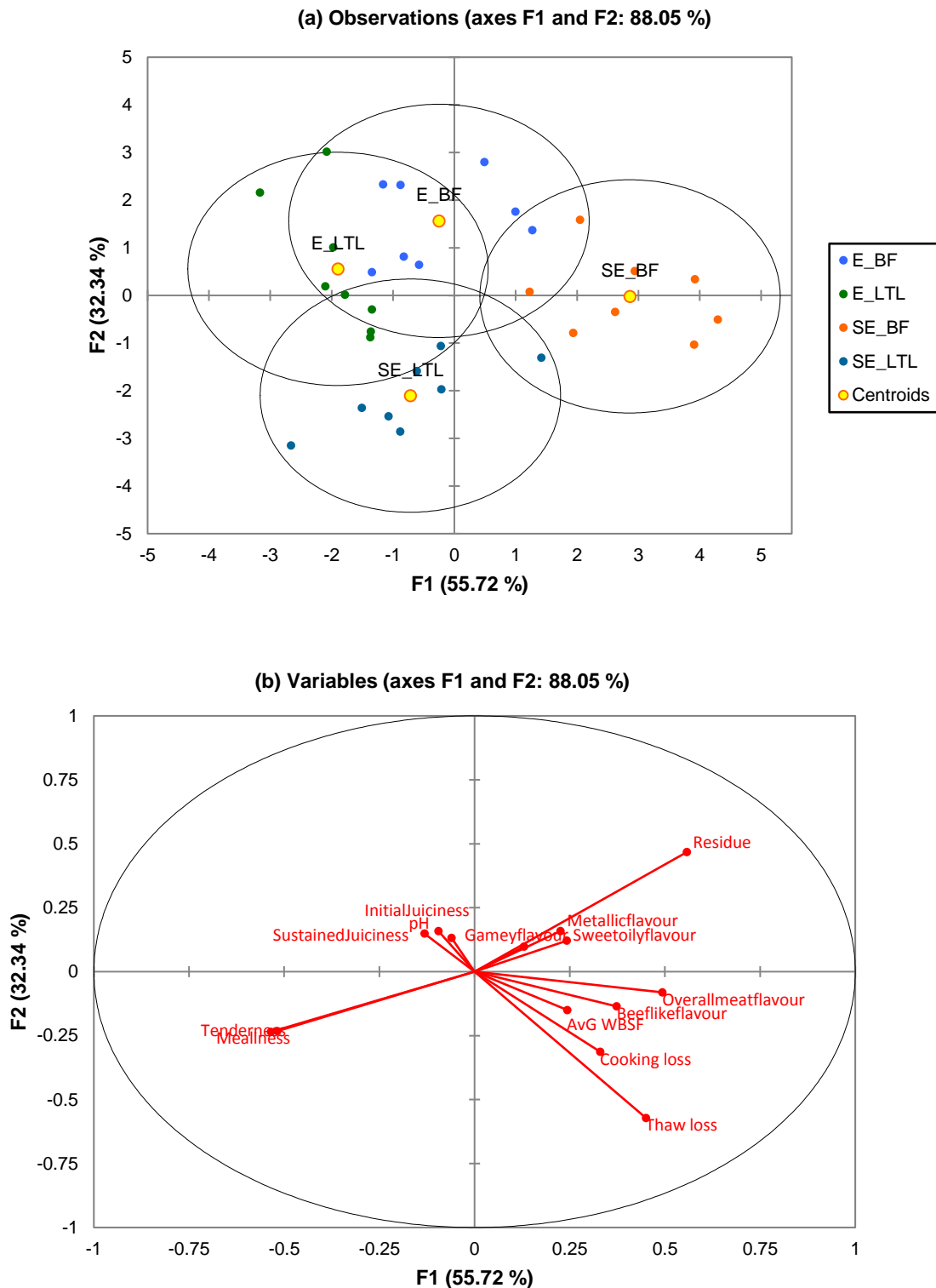


Figure 6.5 DA plot of the (a) mean observations for production system and muscle type for both sensory and instrumental physical variables (SE_LTL, semi-extensive *Longissimus thoracis et lumborum*; SE_BF, semi-extensive *Biceps femoris*; E_LTL, extensive *Longissimus thoracis et lumborum*; E_BF, extensive *Biceps femoris*), with regard to all the sensory and physical variables (b) used for the classification of the observations.

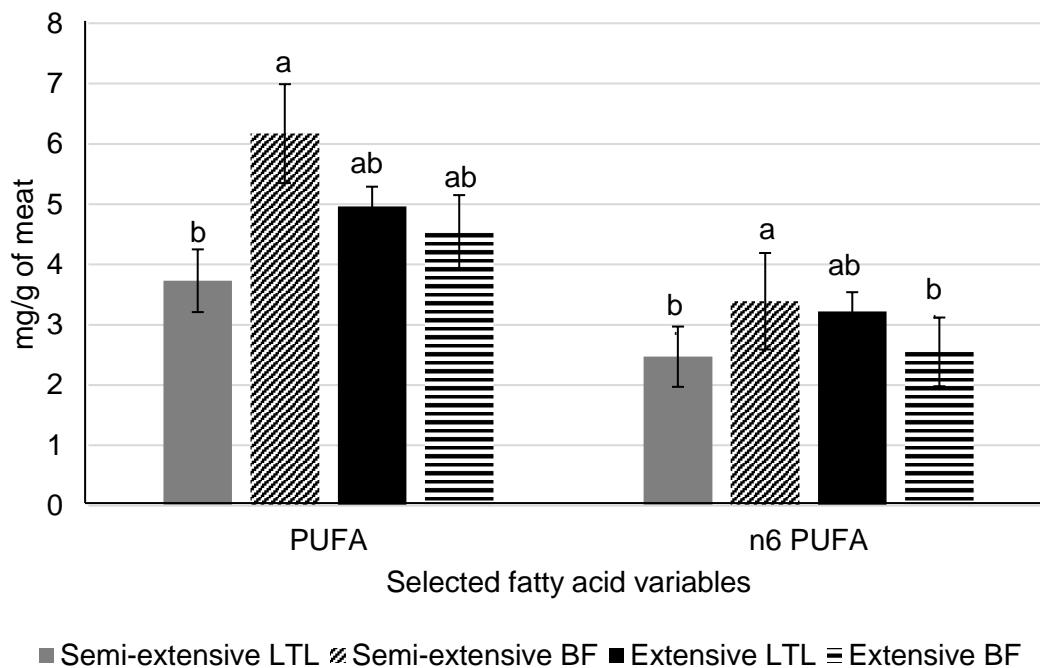


Figure 6.6 Interaction between production system and muscle type for selected fatty acid content (mg/g) of blue wildebeest meat (LSMeans \pm standard error). Means with different superscripts differ significantly at $p \leq 0.05$. LTL= Longissimus thoracis et lumborum; BF= Biceps femoris; PUFA = Total polyunsaturated fatty acids (sum of C18:2n6c, C18:2n6t, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n3, C22:2n6, C22:5n3, C22:6n3); n6 PUFA = Total for omega-6 polyunsaturated fatty acids (sum of C18:2n6c, C18:2n6t, C20:2n6, C20:3n6, C20:4n6, C22:2n6).

Table 6.6 The selected fatty acid profile (%) of blue wildebeest meat as affected by production system, age and muscle type. Values given in LSMean (\pm standard error). Significant differences are highlight in bold ($p \leq 0.05$).

Fatty acid	Production system		p-value	Age		p-value	Muscle		p-value
	Extensive	Semi-extensive		Adult	Sub-adult		LTL	BF	
SFA									
C6:0	nd	nd		nd	nd		nd	nd	
C8:0	nd	nd		nd	nd		nd	nd	
C10:0	nd	nd		nd	nd		nd	nd	
C11:0	nd	nd		nd	nd		nd	nd	
C12:0	nd	nd		nd	nd		nd	nd	
C13:0	0.2 ± 0.06	0.1 ± 0.04	0.092	0.1 ± 0.04	0.2 ± 0.06	0.371	0.2 ± 0.06	0.1 ± 0.05	0.320
C14:0	0.1 ± 0.07	2.0 ± 0.06	0.342	2.0 ± 0.07	0.1 ± 0.06	0.336	2.0 ± 0.02	0.1 ± 0.09	0.689
C15:0	0.4 ± 0.07	0.3 ± 0.06	0.251	0.4 ± 0.06	0.4 ± 0.07	0.745	0.4 ± 0.08	0.4 ± 0.05	0.626
C16:0	0.3 ± 0.03	0.2 ± 0.02	0.403	0.2 ± 0.02	0.2 ± 0.03	0.958	0.2 ± 0.03	0.3 ± 0.02	0.885
C18:0	66.1 ± 2.18	59.5 ± 2.44	0.045	60.1 ± 2.17	65.5 ± 2.55	0.091	64.0 ± 2.41	61.6 ± 2.49	0.456
C20:0	3.3 ± 0.52	5.5 ± 0.66	0.006	5.0 ± 0.59	3.8 ± 0.70	0.103	3.7 ± 0.65	5.1 ± 0.63	0.104
C21:0	nd	nd		nd	nd		nd	nd	
C22:0	nd	nd		nd	nd		nd	nd	
C23:0	nd	nd		nd	nd		nd	nd	
C24:0	1.8 ± 0.29	3.2 ± 0.38	0.005	2.8 ± 0.32	2.2 ± 0.42	0.135	2.1 ± 0.36	2.9 ± 0.37	0.128
MUFA									
C14:1n9c	nd	nd		nd	nd		nd	nd	
C15:1n9t	0.1 ± 0.02	0.1 ± 0.02	0.418	0.1 ± 0.02	0.1 ± 0.02	0.578	0.1 ± 0.02	0.1 ± 0.02	0.464
C16:1n7	0.1 ± 0.02	0.1 ± 0.01	0.604	0.1 ± 0.02	0.1 ± 0.01	0.137	0.1 ± 0.01	0.1 ± 0.02	0.581
C18:1n9c	0.1 ± 0.04	0.1 ± 0.06	0.856	0.1 ± 0.06	0.1 ± 0.04	0.755	0.1 ± 0.06	0.03 ± 0.02	0.419
C18:1n9t	0.02 ± 0.02	0.1 ± 0.05	0.614	0.1 ± 0.05	0.01 ± 0.01	0.345	0.1 ± 0.05	nd	0.191
C20:1n9	0.5 ± 0.02	0.5 ± 0.09	0.737	0.5 ± 0.09	0.5 ± 0.02	0.920	0.5 ± 0.03	0.6 ± 0.08	0.529
C24:1n9	nd	nd		nd	nd		nd	nd	

Abbreviations: *nd* = not detected, LTL= *Longissimus thoracis et lumborum*, BF= *Biceps femoris*.; SFA = Total for saturated fatty acids (sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0); MUFA = Total monounsaturated fatty acids (sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C24:1n9).

Table 6.6 Continued.

Fatty acid	Production system		p-value	Age		p-value	Muscle		p-value
	Extensive	Semi-extensive		Adult	Sub-adult		LTL	BF	
PUFA									
C18:2n6c	15.8 ± 0.86	16.7 ± 0.81	0.513	15.8 ± 0.71	16.7 ± 0.95	0.514	17.0 ± 0.99	15.4 ± 0.61	0.090
C18:2n6t	0.02 ± 0.02	0.1 ± 0.05	0.614	0.1 ± 0.05	0.01 ± 0.01	0.345	0.1 ± 0.05	nd	0.191
C18:3n6	nd	0.03 ± 0.02	0.193	0.01 ± 0.01	0.02 ± 0.02	0.761	0.03 ± 0.02	nd	0.193
C18:3n3	10.0 ± 1.47	9.8 ± 1.22	0.903	11.1 ± 1.15	8.7 ± 1.45	0.149	11.5 ± 1.36	8.3 ± 1.20	0.126
C20:2n6	0.2 ± 0.06	0.3 ± 0.05	0.299	0.2 ± 0.05	0.3 ± 0.06	0.520	0.2 ± 0.06	0.3 ± 0.04	0.098
C20:3n6	nd	nd		nd	nd		nd	nd	
C20:3n3	nd	nd		nd	nd		nd	nd	
C20:4n6	nd	nd		nd	nd		nd	nd	
C20:5n3	nd	nd		nd	nd		nd	nd	
C22:2n6	0.2 ± 0.06	0.3 ± 0.05	0.299	0.2 ± 0.05	0.3 ± 0.06	0.5202	0.2 ± 0.06	0.3 ± 0.04	0.098
C22:5n3	nd	nd		nd	nd		nd	nd	
C22:6n3	1.0 ± 0.21	1.0 ± 0.14	0.895	1.1 ± 0.15	0.9 ± 0.20	0.292	0.8 ± 0.18	1.1 ± 0.16	0.273

Abbreviations: nd = not detected, LTL= *Longissimus thoracis et lumborum*, BF= *Biceps femoris*; PUFA = Total polyunsaturated fatty acids (sum of C18:2n6c, C18:2n6t, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n3, C22:2n6, C22:5n3, C22:6n3).

Table 6.7 The selected fatty acid content (mg/g) of blue wildebeest meat as affected by production system, age and muscle type. Values given in LSMeans (\pm standard error). Significant differences are highlight in bold ($p \leq 0.05$).

Fatty acid	Production system		p-value	Age		p-value	Muscle		p-value
	Extensive	Semi-extensive		Adult	Sub-adult		LTL	BF	
Total IMF (g/100g)	1.8 \pm 0.12	1.7 \pm 0.13	0.664	1.8 \pm 0.12	1.7 \pm 0.13	0.635	1.7 \pm 0.12	1.8 \pm 0.13	
SFA	13.0 \pm 0.97	11.8 \pm 0.80	0.489	12.6 \pm 0.81	12.2 \pm 0.98	0.810	12.0 \pm 0.79	12.7 \pm 1.00	0,480
MUFA	0.1 \pm 0.01	0.1 \pm 0.02	0.611	0.2 \pm 0.02	0.1 \pm 0.01	0.151	0.1 \pm 0.02	0.1 \pm 0.01	0,856
PUFA	4.7 \pm 0.37	4.9 \pm 0.57	0.782	5.2 \pm 0.48	4.5 \pm 0.47	0.377	4.3 \pm 0.56	5.3 \pm 0.34	0,073
PUFA:SFA ratio	0.4 \pm 0.03	0.4 \pm 0.03	0.608	0.4 \pm 0.03	0.4 \pm 0.03	0.512	0.4 \pm 0.03	0.4 \pm 0.03	0,284
n6 PUFA	2.9 \pm 0.24	2.9 \pm 0.29	0.903	3.0 \pm 0.30	2.8 \pm 0.22	0.697	2.9 \pm 0.25	2.9 \pm 0.28	0.737
n3 PUFA	1.9 \pm 0.31	2.0 \pm 0.32	0.704	2.2 \pm 0.28	1.7 \pm 0.32	0.221	1.5 \pm 0.24	2.4 \pm 0.33	0.040
Total fatty acids	17.9 \pm 1.19	16.9 \pm 1.32	0.664	17.9 \pm 0.12	16.8 \pm 0.31	0.634	16.5 \pm 1.23	18.2 \pm 1.26	0,200
n6:n3 PUFA ratio	4.2 \pm 1.37	1.3 \pm 0.19	0.045	2.2 \pm 0.78	3.3 \pm 1.25	0.431	2.6 \pm 0.89	2.9 \pm 1.19	0.823

Abbreviations: *nd* = not detected, LTL= *Longissimus thoracis et lumborum*; BF= *Biceps femoris*; IMF = Total intramuscular fat content; SFA = Total for saturated fatty acids (sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0); MUFA = Total monounsaturated fatty acids (sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C24:1n9); PUFA = Total polyunsaturated fatty acids (sum of C18:2n6c, C18:2n6t, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n3, C22:2n6, C22:5n3, C22:6n3); PUFA:SFA ratio = Total PUFA/Total SFA; n6 PUFA = Total for omega-6 polyunsaturated fatty acids (sum of C18:2n6c, C18:2n6t, C20:2n6, C20:3n6, C20:4n6, C22:2n6); n3 PUFA = Total for omega-3 polyunsaturated fatty acids (sum of C18:3n3, C20:3n3, C20:5n3, C22:5n3, C22:6n3); n6:n3 PUFA ratio = omega-6 (n6 PUFA) to omega-3 (n3 PUFA) fatty acids.

6.4. DISCUSSION

The aim of this study was to determine whether the production system in which blue wildebeest bulls are raised influences the different muscle types with regards the sensory properties and fatty acid profiles. This will aid in the marketing of the meat products obtained from this game species as well as increasing the information on the quality of the meat for consumers as it is important to identify quality differences, if any, based on production system and feeding regime (Wiklund *et al.*, 2003). Consumers expect meat products to have the required nutritional value, be wholesome, fresh, lean and have adequate juiciness, flavour and tenderness (Dransfield, 2003).

The culling of game species can often be stressful due to wild species having inheritable survival instincts making them more susceptible to the effects of stress than domestic species (Hoffman & Wiklund, 2006). When an animal experiences stress it influences the glycogen reserves in the various muscles resulting in a high pH due to more lactic acid being produced from anaerobic glycolysis (Cassens & Cooper, 1971; Kohn *et al.*, 2005). The pH range that is considered normal for red meat is 5.3 to 5.8, with a decrease in sensory acceptance being associated with a pH above this (Devine, Graafhuis, Muir & Chrystall, 1993; Honikel, 2004). In the present study no differences were found in the pH values between the different treatment groups, with the pH values falling within this normal range (pH = 5.6-5.7, Table 6.4). The pH of meat is an important parameter as it influences the water holding capacity (WHC), flavour and tenderness of the final meat product, however since the pH of this study was within the normal range, any negative associations with these attributes should not be attributed to the impact of pH (Honikel, 2004).

In South Africa the game meat industry is primarily operated as a free-market and therefore lacks the infrastructure that is usually provided by a central organisation (Hoffman *et al.*, 2005). This results in culling of game species for meat being restricted to seasonal and environmental conditions and as a consequence game meat is often deboned, vacuum packed and sold as frozen products to prolong its shelf-life (Leygonie *et al.*, 2012a). This was done to the samples analysed in the current study to avoid spoilage before testing. The freezing and thawing that the meat products are subjected to has been reported to influence the water fraction of the meat that results in reduced moisture content of the meat (Dahlan & Hanoon, 2008). Thus as a consequence the WHC and the distribution of moisture in the meat is modified (Leygonie *et al.*, 2012a).

There was no difference in the cooking loss percentage between any of the main effects (Table 6.4), which can be attributed to the standardised cooking and thawing process (Leygonie *et al.*, 2012a). The cooking loss in this study was comparable to that obtained in Chapter 4 that was measured on fresh meat samples. This is in accordance with previous studies that have reported no significant difference in cooking loss between fresh and previously frozen samples (Vieira, Diaz, Martínez & García-Cachán, 2009; Leygonie, Britz & Hoffman, 2012b). This is because water released during cooking loss is caused by the cooking process which causes the melting of fat and

denaturation of proteins that results in the release of chemically bound water which occurs in the same region in the muscle regardless whether fresh or previously frozen (Vieira *et al.*, 2009).

Similarly, there was no difference observed for the initial juiciness and sustained juiciness sensory ratings of the blue wildebeest meat between the different treatments (Table 6.5). Initial juiciness is described as the wetness perceived after the first few chews caused by the release of meat fluids, whereas sustained juiciness is described as the impression formed in the first few chews using molar teeth (Hoffman, Mostert & Laubscher, 2009). The juiciness of meat is related to the intramuscular fat (IMF) content of the meat with a higher level of fat being associated with higher ratings of juiciness and since there was no difference in IMF between the different treatments (Table 6.7), no difference between these sensory attributes were expected.

There was however a significant difference observed for the loss in moisture through thaw loss between the different production systems and age groups (Table 6.4). This could be explained by the differences in nutrition and exercise exhibited by the animals in the different production systems that influence muscle growth and development. The latter also differed between adult and sub-adult animals. Therefore as a consequence there are differences in the composition of fibres and in the distribution of water in the meat of the animals as influenced by different treatments, as water is found in three locations, namely free water, entrapped water and bound water which all contribute to the loss of water (Huff-Lonergan & Lonergan, 2005). However it is important to note that the moisture loss % is very small (0.6 - 1.0%) and a loss of 1 to 2% has been noted as being acceptable (Colle *et al.*, 2015).

The sensory properties that are of importance for consumer-purchase for cooked meat are attributes such as texture/tenderness, juiciness, aroma, taste and flavour (Neethling *et al.*, 2016). With the texture (tenderness, residue, mealiness and juiciness) and flavour sensory attributes often considered by consumers as the most important of the eating quality characteristics (Wiklund *et al.*, 2003). The panel did not detect any differences between the main effects (production system and age) for the tenderness, residue or mealiness of the meat samples. This was unexpected as studies have shown that as the age of an animal increases so the tenderness decreases due to an increase in collagen cross-linkages forming insoluble heat resistant structures (Miller, Tatum, Cross, Bowling & Clayton, 1983). However, a difference in these textual attributes were detected between the two different muscle types assessed ($p \leq 0.05$). The LTL muscle measuring higher for tenderness and mealiness while measuring lower scores for residue than the BF (Table 6.5). The DA plot of the observations (Fig. 6.4 & 6.5) indicates this significant separation. This is attributed to the uniqueness of each skeletal muscle, heterogeneous in the combinations of different muscle fibre types (Cassens & Cooper, 1971). This composition is influenced by function and anatomical location where the LTL is utilised mostly for posture (balance and stability) and the BF located in the hindquarter is utilised for the former as well as walking while grazing and running when threatened (Swatland, 1994).

However, contrary to expectations, no differences were found for the Warner Bratzler shear force between the two muscle types. This can be seen in the DA loadings plot (Fig. 6.5) indicated as AvG WBSF and this was further confirmed by the p-value generated during the ANOVA analysis ($p = 0.554$). The lack of significant differences of tenderness between the muscle types also resulted in a negative correlation between the shear force and tenderness rating by the sensory panel ($r = -0.341$). This correlation however was not significant which is in contrast to previous studies that have recorded a strong significant negative correlation between WBSF and sensory tenderness ratings (Hoffman, Kroucamp & Manley, 2007; North & Hoffman, 2015). This trend also indicates that WBSF values may not always be a good predictor of sensory tenderness. The shear force was higher than expected, falling within the tough category as describe by Miller, Ramsey, Hoover, Carr & Crockett (2001), which is in contrast to that reported in Chapter 4 that was done on fresh meat. This discrepancy could be as a result of the different cooking methods used in the two studies; that in Chapter 4 was done in a water bath whilst that in the present Chapter was done in an oven and positive correlations between shear force and degree of cooking have been reported in literature (Yancey, Apple & Wharton, 2016). The increase in tenderness ratings between the muscle types was found to be linked to the decrease in residue rating, which means that the less tender meat will have more residue (Table 6.5). This is in agreement with findings in literature (Campo *et al.*, 1999; Monsón *et al.*, 2005). It is however, debatable whether the residue ratings in this study can be classified as being 'high', as a very high rating would be closer to 100. There are cases where meat obtained from animals that are produced extensively were ranked lower in tenderness and juiciness than meat produced in semi-extensive systems (Wiklund *et al.*, 2003; Daszkiewicz *et al.*, 2015). This is often related to slower growth rate and less intramuscular fat (Olsson & Pickova, 2005). However, no differences were seen between the production systems with regards to these sensory attributes.

As mentioned previously, gamey, metallic and liver-like aroma and flavours are often perceived as negative sensory attributes. Gamey aroma and flavour have been described by the following descriptions: "an aroma and flavour associated with wild species" (Hoffman *et al.*, 2007; Van Schalkwyk, McMillin, Booyse, Witthuhn & Hoffman, 2011; Hoffman, Jones, Muller, Joubert & Sadie, 2014; North & Hoffman, 2015); "an aroma and flavour associated with a strong game meat aroma and flavour" (Jones, Hoffman & Muller, 2015); and "typical game meat aroma and flavour" (Hoffman *et al.*, 2009). Similarly in this study game aroma and flavour was defined as the aroma and flavour associated with meat from game species that is often linked to liver-like and metallic aroma and flavour. However these three sensory attributes were tested as separate attributes (Table 6.5).

The highest contributor to the overall meat aroma and flavour was gamey aroma and flavour (Table 6.5). This is not only indicated by the high absolute intensity of the gamey aroma and flavour (~67, ~63) relative to the overall meat aroma and flavour (~70) but also the correlation found between the overall aroma and gamey aroma ($r = 0.133$, $p = 0.469$) and overall flavour and gamey flavour ($r = 0.150$, $p = 0.412$). This trend was found for all the main effects (production system, age and muscle

type) tested. However a significant difference was noted for the overall meat aroma between the two production systems, with a higher rating being reported for the meat from the semi-extensive system (Table 6.5). It has been reported that meat with higher proportions of α -linolenic acid (18:3n3) has a more intense aroma than meat with higher proportions of linoleic acid (C18:2n6c) (Wood *et al.*, 1999). However in this study higher concentration of linoleic acid was measured for the meat from the semi-extensive system measuring a lower concentration of α -linolenic acid than the extensive system, with no significant differences between the production systems for these fatty acids. Thus these fatty acid concentrations are not expected to be the cause of the difference in the overall meat aroma between these treatments.

The high contribution of gamey flavour to the overall meat flavour was expected, as previous findings have reported a positive correlation between the intensity of gamey attributes and the polyunsaturated fatty acid (PUFA) content of meat (Geldenhuys, Hoffman & Muller, 2014). In the present study a relatively high PUFA content was measured (Table 6.7). This is attributed to be due to the low fat content associated with this meat (~1.8 g/100g), as the neutral storage lipids tend to have the diluting effect on the predominating unsaturated structural phospholipids (Lawrie & Ledward, 2006). Previous studies have found that gamey flavour to be associated with metallic and liver-like attributes (Maughan, Tansawat, Cornforth, Ward & Martini, 2012; Geldenhuys *et al.*, 2014). This is in agreement with this study with significant correlations between metallic flavour and gamey flavour ($r = 0.651$, $p < 0.0001$), as well as between metallic aroma and gamey aroma ($r = 0.777$, $p < 0.0001$), however liver aroma and flavour obtained zero rating during DSA.

Wiklund *et al.*, (2003) reported that reindeer (*Rangifer tarandus*) that grazed on natural pasture (comparable to extensive game farming in this study) had a more specific gamey flavour due to the larger quantity of natural grazing in their diets linked to the fatty acid composition as the concentration of the fatty acids have an influence on the flavour, however it should be noted that reindeer also browse and would have consumed more aromatic shrubs, etc. This was also confirmed in cattle where those grazed on grass had a higher gamey flavour than those fed on grain (Maughan *et al.*, 2012). It has been reported that in wild fallow deer (*Dama dama*) the meat had higher levels of saturated fatty acids namely, Lauric acid (C12:0) and Arachidic acid (C20:0), whereas the meat of the farmed deer had a higher quantity of Stearic acid (C18:0) and higher total of SFA (Daszkiewicz *et al.*, 2015). In contrast to this, differences in this study were only noted for the saturated fatty acids namely, Arachidic acid (C20:0) and Lignoceric acid (C24:0), with the higher concentrations being seen in the blue wildebeest meat from the semi-extensive system (farmed). Thus only these two fatty acids differed with regards to the main effects, being limited to production system differences. This is attributed to differences in plane of nutrition and activity level which are known to influence fibre type composition and subsequently variations in fatty acid profiles (Wood *et al.*, 2004). It is important to note that blue wildebeest are very selective grazers, while fallow deer can be

predominately grazers or browsers depending on food availability and therefore the differences in diets makes it difficult to compare results between different animal species.

Beef-like was another sensory attribute that contributed greatly to the overall aroma and flavour of the meat in this study indicated by the strong significant correlation between these attributes ($r = 0.474$, $p = 0.006$; $r = 0.324$, $p = 0.071$, respectively). Beef-like aroma has been linked to compounds such as the beefy-meaty peptide (BMP-Lys-Gly-Asp-Glu-Glu-Ser-Leu-Ala) and the concentration of inosine monophosphate (IMP) in the meat, which are compounds that occur naturally in meat (Brewer, 2007).

Previous studies have noted that a high meat aroma that is associated with a high intensity of beef-like, brothy, sweet and brown aromas and flavours are all desirable to consumers (Monsón *et al.*, 2005). A high sweet oily aroma was also associated with the blue wildebeest meat, with differences in this sensory attribute being seen between the two production systems, with higher ratings being recorded for the meat obtained from the semi-extensive production system (Table 6.5). Studies on reindeer have reported that those animals fed commercial feed (as in a semi-extensive system) produced meat with higher intensity scores for sweet aroma and flavour compared to animals that grazed on natural vegetation (Wiklund *et al.*, 2003; Hoffman *et al.*, 2005). In addition higher sweet taste in meat has also been linked to higher pH values of dark-firm-dry (DFD) meat (Byrne *et al.*, 2001). However the meat from this study was classified as normal.

Several studies have been done on the influence on dietary regimes on the composition and sensory qualities of meat from domestic species that can be differentiated by grass vs grain diets (Enser *et al.*, 1998; Van Elswyk & McNeill, 2014). Grasses are high in C18:3n3 (α -linolenic acid) where grains are high in C18:2n6c (Linoleic acid). These are essential fatty acids that cannot be synthesized by the body and therefore should be consumed in human diets (Bézar, Blond, Bernard & Clouet, 1994). Thus as a consequence of this, meat derived from animals fed on grass will have high levels of omega-3 polyunsaturated fatty acids (n3 PUFA) and those fed grain will have high levels of omega-6 polyunsaturated fatty acids (n6 PUFA), respectively. However this is in contrast to this study with the opposite being observed with the meat being high in C18:2n6c (Linoleic acid) compared to C18:3n3 (α -linolenic acid), however both contributed greatly to the total fatty acids present in the meat. This was unexpected as the diets from both production systems consist mainly of grass and blue wildebeest are strictly grazers and therefore higher C18:3n3 (α -linolenic acid) was expected. However the blue wildebeest were culled at the end of summer and it is known that the composition of the forage consumed influences the quantity and quality of the fat present in the meat of ruminant animals, however the composition of the grass consumed by these animals which can be unique for different grass species, was not tested (Warriss, 2000; Van Elswyk & McNeill, 2014). However this is recommended for future studies.

The main fatty acid measured in the study was stearic acid (C18:0). This is in agreement with the findings of Aidoo & Haworth (1995) who identified that stearic acid is among the main fatty acids

in red meat. This fatty acid has been shown to be neutral with regards to plasma LDL cholesterol (Van Elswyk & McNeill, 2014). Fat tissue of ruminants have higher proportions of saturated fatty acids (SFA) and lower polyunsaturated fatty acids (PUFA) than in monogastric animals as the PUFA from forage are hydrogenated in the rumen to less unsaturated or SFA (Wood & Enser, 1997; Webb & O'Neill, 2008). This was confirmed in this study with higher concentrations of total SFA being measured compared to the total PUFA as well as a low PUFA:SFA ratio (~ 0.4 mg/g, Table 6.7). Very low concentrations was however measured for cholesterol-raising fatty acids, which are SFA with carbon chain lengths from C12 to C16 (Van Elswyk & McNeill, 2014).

When considering the nutritional value of meat containing fat, three factors are taken into account: the total fat content; the PUFA:SFA ratio and n6:n3 PUFA ratios (Enser *et al.*, 1998). This study measured a very low total intramuscular fat content (~ 1.8 g/100g, Table 6.7) indicating that meat from this species is lean and healthy. The recommended PUFA:SFA ratio is > 0.7 where the ratio derived from blue wildebeest in the current study is below this (0.4 ± 0.03 mg/g) ratio due to the large contribution of stearic acid (C18:0) to the total SFA resulting in a high total SFA compared to the low total PUFA content. The low PUFA concentration is attribution to the lack of detection of the omega-3 (3n) PUFA (Table 6.7). The lack of detection of these fatty acids could be attributed to the very low total fat content of the meat derived from this species (Table 6.7), the low total lipid content of grass (McDonald *et al.*, 2002) or the low total fatty acids (~ 16 -17 mg/g). Regardless of this, the results of this study was comparable to other wild bovids and antelope namely, buffalo (*Syncerus caffer*, 0.97), blesbok (*Damaliscus pygargus phillipsi*, 0.93), black wildebeest (*Connochaetes gnou*, 1.01) and springbok (0.76) (Hoffman & Wiklund, 2006). For human health, the consumption of omega-3 (n3) fatty acids are very important with a recommended maximum ratio of 4 for omega-6 (n6):omega-3 (n3). In this study a significant difference was reported between the production systems for the n6:n3 ratio (Table 6.7). This is due to very low omega 3 PUFA being measured in the meat from the extensive production system. However the results were still within the recommended guidelines and compared well with other game species such as kudu (*Tragelaphus strepsiceros*, 3.76) and impala (*Aepyceros melampus*, 2.22) (Hoffman, Mostert & Laubscher, 2009).

6.5. CONCLUSION

Production system, age and muscle type had minor influences on the sensory properties and fatty acid profiles of blue wildebeest bulls. Gamey aroma was the highest contributor to the overall aroma and flavour that was significantly correlated with metallic aroma and flavour, where the high PUFA content could have been involved in producing the intense gamey aroma and flavour notes. These two sensory attributes have previously been positively correlated to the dislike of consumers. However gamey aroma and flavour did not differ significantly from the strong contribution of beef-like aroma and flavour to the sensory profile of blue wildebeest, which contrasting to the previous statement, has been positively correlated to the preference of consumers. In addition to this, the

sweet aroma and flavour also greatly contributed to the sensory ratings of the blue wildebeest meat which in addition to beef-like attributes is desirable to consumers. The blue wildebeest meat was low in tenderness (high shear force) which could be attributed to the cooking method. The meat was associated with a relatively moderate initial juiciness and sustained juiciness attributed to the low cooking loss and thaw loss despite a very low intramuscular fat content of the meat. Differences in fatty acid profiles were attributed more to differences in production systems (differences in diets and activity) than age or anatomical location of muscles. The meat exhibited the desired fatty acid profile that is recommended and therefore can be concluded as being healthy and lean. This research essentially categorises the sensory profile of blue wildebeest which allows for the incorporation of meat from this species as a meat product of desirable attributes on the South African meat market. This initial profile allows for further research to determine the effects of factors such as sex, season of harvest and other production systems on the meat quality of blue wildebeest.

6.6. REFERENCES

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CHAPTER 7

YIELD AND MEAT QUALITY OF SEMI-EXTENSIVELY PRODUCED BLUE WILDEBEEST (*Connochaetes taurinus*) BULLS

ABSTRACT

The aim was to determine the carcass yield, physical characteristics and chemical composition of six muscles (*Longissimus thoracis et lumborum*, *Biceps femoris*, *Semimembranosus*, *Semitendinosus*, *Infraspinatus* and *Supraspinatus*) obtained from blue wildebeest bulls raised at the same level of feeding and slaughtered at 28 months age. Eight blue wildebeest bulls were obtained from a semi-extensive production system that had a mean undressed carcass weight of 234.1 ± 5.55 kg, a mean carcass weight of 125.4 ± 3.18 kg and a dress out percentage of $53.6 \pm 0.56\%$. The carcasses produced a mean of 100.0 kg offal (internal and external) and a total mean of 21.7 kg for the six main carcass muscles studied. The physical meat quality parameters were influenced by muscle type, with the exception of the ultimate pH. The forequarter muscles (IS and SS) were found to be desirable with regards to drip loss, cooking loss, Warner Bratzler shear force and intense bright red colour in comparison to the hindquarter muscles. However all six muscles studied were within the measured range for all physical parameters that are considered to be associated with good quality meat. For the chemical analyses it was found that the hindquarter muscles had a lower moisture content, higher protein content and lower intramuscular fat (IMF) content than the forequarter muscles. The results obtained in the study therefore show that blue wildebeest bulls of the same age produced in a semi-extensive farming system has the potential to produce meat of good quality, as well as being a lean and healthy alternative protein source.

Keywords: Game meat, Blue wildebeest, Carcass yields, Physio-chemical meat quality

7.1. INTRODUCTION

Presently South Africa has one of the fastest growing agricultural industries due to the success of game and scarce game breeding (Taylor, 2016). The industry consists of over 10 000 wildlife production properties covering about 20 million ha of land, with a high annual conversion rate from conventional livestock farming to game farming (Taylor, 2016; Otieno & Muchapondwa, 2016). Therefore the game industry is recognised as an organised commercial enterprise in the agriculture sector of South Africa.

The success of this industry is attributed to game farming proving to be more ecologically and financially sustainable compared to traditional livestock farming in a country with low and irregular rainfall, high evaporation rates and poor or shallow soils (Furstenburg, 2002). In order for any agricultural business to thrive, it is important to find alternative ways in which to utilize all the available land that is not economically viable. Since game animals are better adapted physiologically than livestock to efficiently utilize natural vegetation due to lower nutritional requirements, better at withstanding excessive heat, able to survive on limited water supply and resistant to most diseases and parasites, it makes them better suited to succeed in the semi-arid regions of South Africa (Cole, 1990). Game animals are characterized as high value, capable of being utilized for multiple commodities (consumptive and non-consumptive) as well as having higher stocking rates than domestic livestock, which further encourages their farming (Berry, 1986; Bothma & Van Rooyen, 2005).

Due to the success and popularity of game farming, various combinations of farming systems have developed to optimise animal production. Most common is the semi-extensive production farming system. This type of production system involves keeping animals in small camps/paddocks, however large enough to allow free movement and natural herd behaviour, while reducing the risk of predation and disease, thus implementing livestock farming principles while still addressing the natural limitations of individual game species (Furstenburg, 2002). In order to maintain habitat integrity, optimize production and maintain the health of the animals, they are subjected to supplementary feeding, provided with water and may undergo veterinary intervention if required (Du Toit, Van Niekerk & Meissner, 2013; Oberem & Oberem, 2016). The primary objective of this type of farming is to breed animals of optimum quality for live sales or trophy hunting, therefore the breeding programs implemented makes use of behavioural manipulation. This is when a selected individual with advantageous characteristics such as longer horn length or variations in coat colour are chosen to breed with in order to produce offspring with desired genetic quality, while the remaining breeding aged males are removed (Lindsey *et al.*, 2013).

The sub-standard stock that is removed are utilised either for biltong and recreational hunting, live sales or meat production (Berry, 1986). When an index based on animal numbers was developed the weighted net values showed that meat production was the most profitable of all the

game production sectors, providing the highest return per unit area (Berry, 1986). Therefore the surplus or sub-standard stock that is the by-product of a breeding program are suitable for meat production as they simply utilize the habitat while filling up roaming space and carrying capacity whilst not contributing to reproduction (Furstenburg, 2002; Bezuidenhout, 2012).

Amongst the game species that have shown to thrive in a semi-extensive production system is blue wildebeest (*Connochaetes taurinus*) (Personal communication with a blue wildebeest farmer, B. York). These animals are used in the breeding of the golden wildebeest (*Gnu*), which is a naturally occurring colour variant and not a sub-species of the blue wildebeest. This is because the golden coat colour of the golden wildebeest is thought to be caused by the expression of a recessive gene where the blue colour is the expression of the gene in its dominant form, however the gene expression is complex and not yet fully understood (Smith, 2013). Therefore they are exactly alike in physical, biological, habitat and social characteristics differing only with regards to their physical colour appearance. In the breeding of golden wildebeest, blue wildebeest males are often subjected to regular culling as to allow males of a specific colour to become dominant, thus male blue wildebeest are suitable for meat production (Bezuidenhout, 2012). Often, these animals have just become sexually mature when they are removed from the herd, which happens at about 2 years of age (Estes, 1991).

Before an animal can be considered for meat production, essential information must be available in terms of production potential, physical meat quality and nutritional composition in order for it to compete with existing meat products (Hoffman, Muller, Schutte, Calitz & Crafford, 2005; Hoffman & Cawthorn, 2013). With consumers driving the meat market with demands of healthy, nutritious and consistent quality products, it is important for producers to respond to these consumer requirements to successfully enter the meat market. In this study the production potential, carcass composition, physical characteristics and chemical composition of six muscles obtained from blue wildebeest bulls raised at the same level of feeding and slaughtered at similar ages (28 months) after being removed from the breeding herd were compared.

7.2. MATERIALS AND METHODS

7.2.1. Animals and study location

A total of eight blue wildebeest (*Connochaetes taurinus*) bulls aged 28 months were randomly culled from a herd of 300 bulls that has been selected for culling as their horns did not reach the required minimum that was acceptable for stud breeding. However, there was no indication that their carcasses were inferior to that of the breeding stud bulls. This age is the age at which the breeding potential of the bulls has been established and a final selection for breeding or culling is made.

The semi-extensive farming system, Sandstone valley (S 24°33,764' – E026°02,510') was situated in the Modimolle region in the Limpopo province, South Africa. This area is classified as the

Central Sandy Bushveld vegetation unit. This veld type is characterised with gentle sloping hills and hallows found between mountains and sandy plains with tall woodland trees. It has a grass dominating herbaceous layer with relatively low basal cover on dystrophic sands (Mucina & Rutherford 2006). These animals were blue wildebeest splits which are individuals that carry the genes for the recessive golden colour. Animals ($n \sim 300$) were maintained in a breeding camp of 600 ha, consisting of only bulls, and fed a daily ration of 3 kg/animal of a strategic supplementary feed (mixed using a on farm mixer to form a homogenous ration). The formulation of the supplementary feed at point of harvest was: grass (33.99%), maize (15.69%), Brewers grain (12.5%), molasses (12.55%), soya oil cake (7.32%), wheat (6.24%), cotton oil cake (5.23%), Lucerne (3.92%), lime (0.94%), phosphate trace-mineral supplement - high in monocalcium phosphate - (0.94%), mineral premix (0.34%), and salt (0.26%). This typical diet varies with regards to availability of the main ingredients. The two farms were approximately 45 km from each other.

7.2.2. Culling and dressing

The animals were culled/harvested during the day using a 0.308 calibre rifle with a sound suppressor by a marksman on the back of a secure hunting vehicle, to minimise the stress of the animals. All procedures performed during culling, slaughtering and dressing were done as according to Van Schalkwyk & Hoffman (2016). The horns were measured in inches as is done in the industry using a flexible ¼ inch plastic measuring tape (Schwabland & Barnhart, 2016). The dressed warm carcass was stored overnight in a cold room at 4°C to undergo rigor.

Refer to Material and Methods of Chapter 3.2.2 for more details.

7.2.3. Sample preparation

After ~24 hours of cooling, the forequarter muscles *Infraspinatus* (IS) and *Supraspinatus* (SS); hindquarter muscles *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) were removed in their totality and the loin muscle *Longissimus thoracis et lumborum* (LTL) removed from between the last lumbar vertebra and the natural termination of the muscle at the cervical vertebra. Both the right and left side muscles were removed. Each muscle was weighed and a portion of the muscle (based on a randomisation function run on excel) was cut perpendicular to the longitudinal axis of the muscle to give approximately equal portions/steaks. On the cranial part of the portion, physical analyses were performed immediately, while the caudal part of the portion was kept for chemical analyses and stored at $-2.6 \pm 0.07^\circ\text{C}$ under vacuum until reaching Stellenbosch University laboratory where it was frozen at -20°C until analysis.

7.2.4. Physical analyses

For the physical analyses, three ~1.5 cm thick steaks were cut perpendicular to the longitudinal axis from the centre of the muscle portion on which the following analyses were performed: Acidity (pH_U), moisture loss, Warner Bratzler shear force and surface colour.

Refer to Materials and Methods of Chapter 4.2.4 for a detailed explanation on the various procedures used to determine the physical parameters.

7.2.5. Chemical analyses

The samples were prepared and the proximate analysis performed as explained in the Materials and Methods of Chapter 5.2.4.

7.2.6. Statistical analyses

The carcass yield, offal yields and horn data was determined using descriptive statistics as indication of the expected variation. For the muscle weight, physical attributes (pH_U, colour, moisture loss and tenderness) and proximate analysis (moisture, protein, intramuscular fat (IMF) and ash content) data was analysed by performing an univariate analysis of variance (ANOVA) using the General Linear Models (GLM) procedures of SAS software (Version 9.4; SAS Institute Inc., Cary, USA), with animal as block replicates for muscles.

A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). Where there was significant deviation from normality, such when the standardised residual for an observation deviated with more than three standard deviations from the mean value, outliers were evaluated and where applicable, removed. To compare the means, a Fisher's t-least significant difference was calculated (Ott, 1998). A 5% probability level was considered significant for all tests testing significance. The values are reported as the Least Square Means and standard error.

7.3. RESULTS

7.3.1. Meat production potential

7.3.1.1. Carcass yields

Carcass yields were measured to determine the meat production potential of blue wildebeest bulls aged 28 months from a semi-extensive production system. The mean, minimum and maximum undressed (bled) blue wildebeest weights, dressed carcass weights and dressing percentages are presented in Table 7.1.

Table 7.1 Carcass yields obtained from 28 month old blue wildebeest bulls. Results reported as LSMeans, minimum and maximum weights and Standard Error of the Mean (SEM).

		Mean (<i>n</i> = 8)	Minimum (<i>n</i> = 8)	Maximum (<i>n</i> = 8)	SEM
Bled, undressed carcass	kg	234.1	205.0	255.0	5.55
Carcass weight	kg	125.4	108.0	139.8	3.18
Dressing percentage [#]	%	53.6	50.5	55.8	0.56

[#] The percentage of the live animal weight which is the carcass as determined by dividing the hot-carcass-weight by the live animal weight.

7.3.1.2. Offal yields

The mean external offal and visceral organ yields of the blue wildebeest bulls are presented in Table 7.2. The total visceral organs (24.8%) had a higher percentage contribution than the external offal yields (17.8%) to the undressed carcass weight. Of the external offal, the skin (8.6%) had the highest percentage contribution followed by the head (including horns and tongue) (7.2%) followed by the legs (from the elbow joint down) (2.0%). For the visceral organs, the gastrointestinal tract (GIT – includes stomach and intestines) (21.4%), had the highest percentage contribution while the spleen (0.2%) having the lowest percentage contribution to the undressed carcass weight. The overall contribution of the external and visceral offal to the undressed carcass weight for blue wildebeest aged 28 months was 42.7%.

7.3.1.3. Muscle yields

The mean weight and percentage contributions relative to the blue wildebeest bulls' carcass weight of the six selected muscles (combined right and left side) are presented in Table 7.3. The highest percentage contribution to the cold carcass weight was seen for the BF muscle (5.0%), while the lowest was for the SS muscles (1.2%). The total contribution of the selected muscles to the carcass weight was 17.3%.

7.3.1.4. Horn measurements

Horn lengths of each individual animal were measured as ultimately the horn size of the animal determines the value of the live animal with colour being a multiplying factor. Therefore the horn lengths of each individual animal was presented in Figure 7.1. No statistically significant differences between the different animals for the different horn measurements were present. The mean horn measurements are presented in Table 7.4. The left base (14 in) was longer in length than the right base (13 5/8 in). Similarly, the left horn length (23 1/8 in) was longer than the right horn length (22 5/8 in). The total length of the horns (see method of measuring in Figure 3.1) was 53 3/8 in.

Table 7.2 LSMeans, minimum and maximum offal contributions (kg and %) to the undressed carcass weight of 28 month old blue wildebeest bulls. ($n = 8$).

Offal parts		Mean	Min	Max	SEM
Undressed carcass	kg	234.1	205.0	255.0	5.55
Head ^{#1}	kg	17.0	15.2	19.2	0.56
	%	7.2	6.6	7.9	0.15
Legs	kg	4.7	4.1	5.1	0.12
	%	2.0	1.9	2.1	0.02
Skin	kg	20.3	16.0	22.5	0.73
	%	8.6	7.8	9.2	0.17
Total external offal	kg	41.9	35.2	46.7	1.40
	%	17.8	16.3	19.2	0.22
Heart	kg	1.4	1.1	1.8	0.07
	%	0.6	0.5	0.7	0.03
Lungs	kg	3.2	2.1	4.4	0.29
	%	1.4	1.0	1.8	0.10
Liver	kg	2.1	0.4	2.5	0.25
	%	0.9	0.2	1.0	0.10
Kidneys	kg	0.7	0.4	2.4	0.25
	%	0.3	0.2	1.2	0.13
Spleen	kg	0.6	0.5	0.7	0.02
	%	0.2	0.2	0.3	0.01
GIT ^{#2}	kg	50.1	42.5	56.8	1.50
	%	21.4	19.5	23.4	0.56
Total internal offal	kg	58.0	49.8	65.5	1.72
	%	24.8	22.6	26.9	0.63
Total	kg	99.9	89.1	109.8	2.52
	%	42.7	40.6	45.2	0.56

^{#1}Head: includes tongue and horns.^{#2}GIT: Gastro-intestinal tract, includes stomach and intestines.

Variable % = contribution to the undressed carcass weight.

Table 7.3 LSMean, minimum and maximum muscle contributions (kg and %) (Combined right and left side) to the carcass weight from blue wildebeest bulls ($n=8$).

Muscle type		Mean	Min	Max	SEM
Cold carcass	kg	125.4	108.0	139.8	3.18
LTL	kg	5.9	4.5	7.7	0.35
	%	4.7	4.1	5.5	0.18
BF	kg	6.3	5.9	6.9	0.12
	%	5.0	4.8	5.4	0.09
SM	kg	4.5	3.8	4.8	0.12
	%	3.6	3.3	3.9	0.07
ST	kg	1.8	1.6	2.1	0.06
	%	1.4	1.3	1.5	0.03
IS	kg	1.7	1.4	2.1	0.08
	%	1.4	1.2	1.5	0.04
SS	kg	1.5	1.3	1.8	0.06
	%	1.2	1.0	1.3	0.03
Total	kg	21.7	18.3	25.0	0.79
	%	17.3	15.8	19.2	0.20

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*, SEM = standard error of the mean.

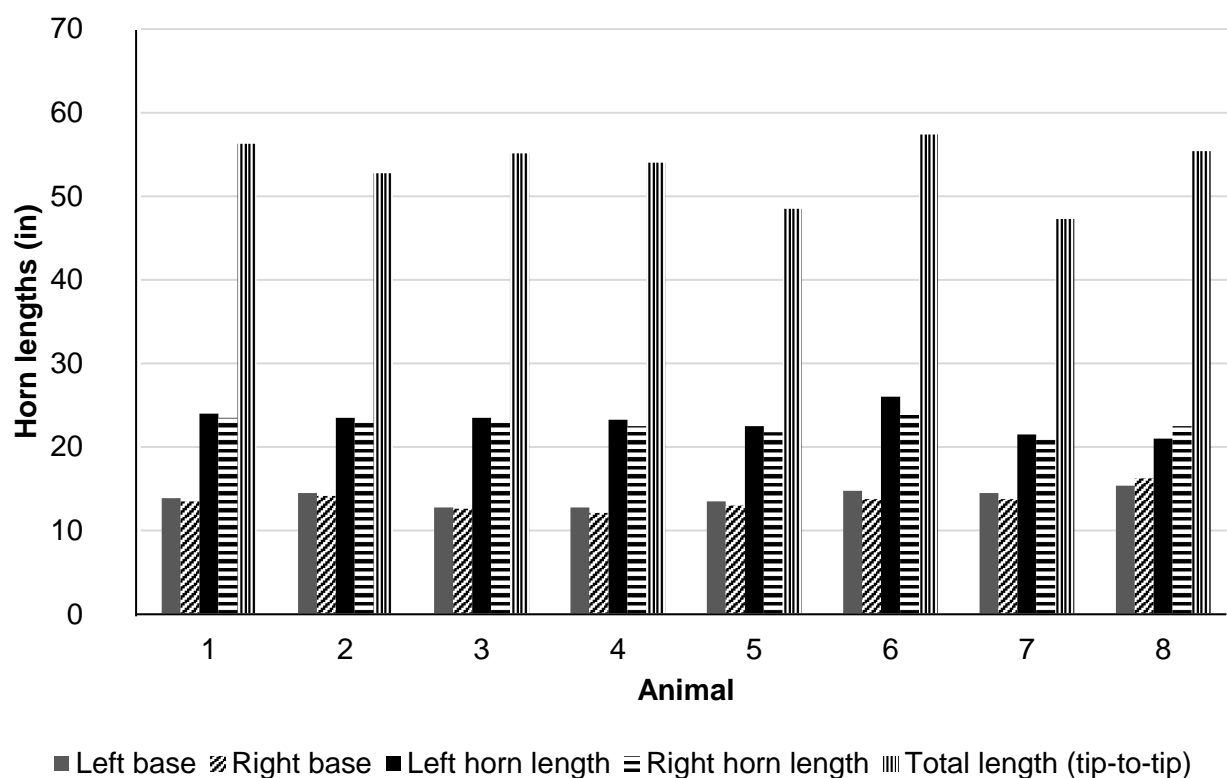


Figure 7.1 The mean horn measurements (inches) for each individual blue wildebeest.

Table 7.4 The mean horn measurements (inches) for the blue wildebeest.

		Mean	Min	Max	SEM
Left base	in	14	12 6/8	15 3/8	0.34
Right base	in	13 5/8	12 1/8	16 4/8	0.44
Left horn length	in	23 1/8	21	26	0.55
Right horn length	in	22 5/8	21	24	0.34
Length (from tip to tip)	in	53 3/8	47 2/8	57 3/8	1.29

Length: Measurement started on the tip of the left horn along the horn thread, across the base, to the tip of the right horn.

7.3.2. Physical analyses of the muscles

For the physical analyses of the six muscles, three ~1.5 cm thick steaks were cut perpendicular to the longitudinal axis from the centre of the muscle portion.

There was no significant difference between the different muscle types for the ultimate pH (pH_U) measured ~24 hours post mortem (Table 7.5). The pH_U was numerically higher in the

forequarter (IS and SS) muscles, with a numerically slightly lower pH_U being measured in the remaining four muscles.

For drip loss, there was a significant difference ($p = 0.002$) between the different muscle types (Table 7.5). The drip loss was higher for the SM ($1.6 \pm 0.23\%$), LTL ($1.5 \pm 0.20\%$) and ST ($1.1 \pm 0.14\%$) muscles, while a lower drip loss was associated with the BF ($1.0 \pm 0.14\%$) and the forequarter muscles (IS = $0.9 \pm 0.04\%$; SS = $0.9 \pm 0.09\%$). A significant difference between the selected muscle types for cooking loss was also observed. The highest ($p \leq 0.05$) cooking loss was recorded in the ST ($39.5 \pm 0.76\%$) compared to the other muscles. The lowest ($p \leq 0.05$) cooking loss was measured in the IS ($31.1 \pm 1.08\%$).

The shear force values differed ($p \leq 0.05$) between the different muscles types (Table 7.5) in the following descending order: SM (4.6 ± 0.50 kg/1.27cm Φ ; 35.8 ± 3.90 N), BF (4.1 ± 0.44 kg/1.27cm Φ ; 31.9 ± 3.44 N), ST (3.9 ± 0.29 kg/1.27cm Φ ; 30.3 ± 2.27 N), LTL (3.5 ± 0.41 kg/1.27cm Φ ; 26.9 ± 3.19 N), SS (3.2 ± 0.38 kg/1.27cm Φ ; 24.7 ± 2.91 N) and IS (2.7 ± 0.31 kg/1.27cm Φ ; 20.9 ± 2.40 N). The latter being the most tender.

The colour of the fresh meat was measured ~24 hours post mortem. A significant difference between the different muscle types was observed for all the colour parameters measured (Table 7.6). The mean L* value was higher ($p \leq 0.05$) for the ST (35.4 ± 0.06) compared to the other muscle types which did not differ from each other.

The highest a* values were observed in the forequarter (IS and SS) muscles. However these muscles did not differ significantly from the a* value measured in the SM. Significantly ($p \leq 0.05$), the lowest a* value was recorded in the LTL. Similarly, the Chroma values were higher ($p \leq 0.05$) in the IS, SS and SM with the lowest Chroma value being measured in the LTL.

The highest b* values was measured in the SM, ST, IS and BF, while the lowest being measured in the SS and LTL, with the latter two muscles not differing significantly between IS and BF. For the hue-angle the highest value was measured in the ST, not differing from the SM, while the lowest ($p \leq 0.05$) hue-angle was measured in the SS (that did not differ from the IS).

7.3.3. Chemical analyses

7.3.3.1. Proximate analysis

Table 7.7 depicts the proximate composition of the six blue wildebeest muscles. The SS had the highest mean moisture content that did not differ from the moisture content measured in the ST or IS. Significantly ($p \leq 0.05$), the lowest moisture content was measured in LTL. This muscle also had the highest ($p \leq 0.05$) protein ($22.9 \pm 0.31\%$) content. The lowest ($p < 0.05$) protein content was measured in the IS and SS ($20.4 \pm 0.31\%$). These two forequarter muscles (IS and SS) also had the highest intramuscular fat (IMF) content ($2.1 \pm 0.31\%$ and $2.2 \pm 0.31\%$, respectively) although the level of IMF did not differing significantly from that of the BF ($1.8 \pm 0.31\%$). There was no significant

difference in the ash content (1.1%) between the different muscle types of the 28 months old blue wildebeest bulls.

Table 7.5 LSMean (\pm standard error) for the physical meat parameters (pH_U, moisture loss and shear force) measured in six blue wildebeest muscles. Significant differences are highlight in bold ($p \leq 0.05$).

Parameter	Muscle type						p-value
	LTL	BF	SM	ST	IS	SS	
pH _U	5.9 \pm 0.11	5.9 \pm 0.13	5.9 \pm 0.15	5.9 \pm 0.10	6.0 \pm 0.10	6.0 \pm 0.14	0.271
Drip loss (%)	1.5^{ab} \pm 0.20	1.0^c \pm 0.14	1.6^a \pm 0.23	1.1^{bc} \pm 0.14	0.9^c \pm 0.04	0.9^c \pm 0.09	0.002
Cooking loss (%)	34.8^c \pm 0.97	35.0^c \pm 1.44	38.0^b \pm 1.32	39.5^a \pm 0.76	31.1^d \pm 1.08	37.0^b \pm 1.43	<.0001
Shear force (kg/1.27cm Φ)	3.5^{bc} \pm 0.41	4.1^{ab} \pm 0.44	4.6^a \pm 0.50	3.9^{abc} \pm 0.29	2.7^d \pm 0.31	3.2^{cd} \pm 0.38	0.0002
Shear force (N)	26.9^{bc} \pm 3.19	31.9^{ab} \pm 3.44	35.8^a \pm 3.90	30.3^{abc} \pm 2.27	20.9^d \pm 2.40	24.7^{cd} \pm 2.91	0.0002

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

^{a-d} Row means with different superscripts differ significantly at $p \leq 0.05$.

Table 7.6 LSMean (\pm standard error) for the meat quality colour parameters of six selected blue wildebeest muscles.

Parameter	Muscle type						p-value
	LTL	BF	SM	ST	IS	SS	
L*	31.7 ^b \pm 0.93	32.0 ^b \pm 85	31.8 ^b \pm 1.22	35.4 ^a \pm 0.06	31.2 ^b \pm 0.59	30.1 ^b \pm 0.95	0.0002
a*	11.9 ^d \pm 0.48	13.1 ^{bc} \pm 0.51	13.7 ^{ab} \pm 0.73	12.3 ^{cd} \pm 0.30	14.4 ^a \pm 0.39	14.5 ^a \pm 0.57	<.0001
b*	7.7 ^b \pm 0.62	8.4 ^{ab} \pm 0.56	9.5 ^a \pm 0.77	9.2 ^a \pm 0.35	8.7 ^{ab} \pm 0.35	8.0 ^b \pm 0.43	0.020
Chroma	14.2 ^d \pm 0.71	15.6 ^{bc} \pm 0.68	16.7 ^{ab} \pm 1.00	15.4 ^c \pm 0.42	16.9 ^a \pm 0.34	16.6 ^{abc} \pm 0.68	0.0004
Hue-angle	32.5 ^b \pm 1.37	32.6 ^b \pm 1.25	34.2 ^{ab} \pm 1.14	36.8 ^a \pm 0.73	31.3 ^{bc} \pm 1.40	28.8 ^c \pm 0.88	0.0003

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

^{a-d} Row means with different superscripts differ significantly at $p \leq 0.05$.

Table 7.7 Proximate analysis (g/100 g) of six selected blue wildebeest muscles. Values given as LSMean (\pm standard error). Significant differences are highlight in bold ($p \leq 0.05$).

Parameter	Muscle type						p-value
	LTL	BF	SM	ST	IS	SS	
Moisture	75.4^d \pm 0.36	76.5^{bc} \pm 0.37	75.7^{cd} \pm 0.44	77.3^{ab} \pm 0.39	77.5^{ab} \pm 0.27	77.5^a \pm 0.18	0.0002
Protein	22.9^a \pm 0.31	22.5^{bc} \pm 0.31	22.5^{ab} \pm 0.48	21.2^c \pm 0.39	20.4^{dc} \pm 0.38	20.4^d \pm 0.38	<.0001
IMF	1.5^{bc} \pm 0.13	1.8^{ab} \pm 0.22	1.6^{bc} \pm 0.12	1.3^c \pm 0.14	2.1^a \pm 0.20	2.2^a \pm 0.11	0.002
Ash	1.1 \pm 0.03	1.1 \pm 0.02	1.1 \pm 0.03	1.1 \pm 0.14	1.1 \pm 0.02	1.1 \pm 0.03	0.813

Abbreviations: IMF= intramuscular fat, LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*. ^{a-d} Row means with different superscripts differ significantly at $p \leq 0.05$.

7.4. DISCUSSION

The first part of this study sought to determine the carcass yields of blue wildebeest bulls aged 28 months obtained from a semi-extensive production system. The undressed carcass weights had a mean weight of 234.1 kg, taking the standard error of the mean (SEM) of 5.55 into account, it can be concluded that the true population mean for undressed carcass weight lies between 228.55 kg and 239.65 kg. In a previous study on blue wildebeest it was found that the mean undressed carcass weight was ~170 kg (Hoffman, Van Schalkwyk & Muller, 2011). The latter being observed in an extensive production system, consisting of both adult and sub-adult animals, that roamed freely and depended only on natural vegetation. Therefore the high plane of nutrition that the animals in the current study receive daily ensures optimal growth and development of muscle resulting in the animals reaching their mature weight at an earlier age (Estes, 1991). Similarly, the true population mean for the carcass weight of 28 month old blue wildebeest bulls lies between 122.22 kg and 128.58 kg, significantly higher than observed by Hoffman *et al.* (2011) (~88 kg) which could be explained by the impact of age in the later study. Knowledge of the actual carcass weight is important in the industry as game meat is typically sold as price per carcass weight unit. Sometimes, the carcass weight could include the skin-on carcass weight as game carcasses are typically transported with skin on to minimise dehydration of the carcasses as only few African game species have a subcutaneous fat layer. Therefore, in this scenario the skin weight (~20.3 kg; Table 7.2) would need to be added to the carcass weight and an adjusted price per weight unit calculated.

When determining the yield of an animal, the most important principle to consider is the dressing percentage. According to this study the true population mean dressing percentage of 28 month old blue wildebeest bulls lies between 54.04% and 54.16%. This is comparable to previous studies on blue wildebeest (54.9%) harvested during 1973 and 1974 at the Hluhluwe Game Reserve, KwaZulu Natal (Attwell, 1982). However, it is higher than 51.6% measured for blue wildebeest harvested in 2001 and 2003 at the Sandveld Nature Reserve (Hoffman *et al.*, 2011). A possible explanation for the low dressing % obtained in the latter study, is that the study consisted of both bulls and cows, where cows are known to be physically smaller than bulls. The animals of different ages were also used in the study. When the dressing percentage of the current study is compared to other African antelope species, it compares favourably with blesbok (*Damaliscus pygargus phillipsi*) (52.2%) (Hoffman, Smit & Muller, 2008) and black wildebeest (*Connochaetes gnou*) bulls (53.1%) (Hoffman, Van Schalkwyk & Muller, 2009). When compared to domestic livestock, the dressing percentage is comparable to the 50.3-53.8% reported for Nguni, Bonsmara and Angus (Muchenje *et al.*, 2008). However, it is important to note that the high dressing percentage of cattle is achieved at higher fat percentages compared to blue wildebeest (Ledger, 1963). Of particular note is the higher weights of kidney fat and subcutaneous fat in domestic animals that contribute to their dressing percentage.

Edible by-products such as visceral organs (heart, lungs, liver and kidneys) and external organs (heads and feet) are produced during the harvesting of game species (McCrindle *et al.*, 2013). These products have formed part of the traditional diets in South Africa for centuries as it is a form of low-cost protein (Erasmus & Hoffman, 2017). The liver is also a crucial source of vitamin A and folic acid, thus offal is also an important source of micronutrients (Biesalski, 2005). A high percentage contribution of the mean total visceral organs (~24.8%; ~58.0 kg) to the mean undressed carcass weight (234.1 kg) was mainly contributed by the head weight (17.0 kg; Table 7.2). This was expected due to the large horns, with a mean length of 53 3/8 in, that are typical of this species. From the muscle weight results it can be seen that the different muscles are extremely variable, differing in size and weight, thus it is expected that they would differ in meat quality traits due to muscle fibre composition (Joo, Kim, Hwang & Ryu, 2013).

There was no significant difference in the ultimate pH (pH_U) of the different muscles types, however the pH_U of the current study ($pH_U = 5.9 - 6.0$) was higher than is usually considered normal post-mortem ($pH_U = 5.3 - 5.8$) (Honikel, 2004). The higher pH_U recorded in this study could be attributed to stress experienced by the animals during the day time culling, as harvesting animals at night has been shown to be the least stressful harvesting method (Von La Chevallerie & Van Zyl, 1971; Kritzing *et al.*, 2003; Hoffman & Wiklund, 2006). However due to the need for selective culling based on age, day culling allows the marksman to clearly distinguish between age which allows for a more selective culling to be possible (Hoffman & Laubscher, 2009). The pH_U range established in the current study is however still considered optimal for meat as a $pH_U > 6.00$ is considered to negatively influence consumer perceptive in relation to the meat colour, variation in tenderness as well as shelf life (Frylinck *et al.*, 2013; Shange *et al.*, 2018).

Since muscles are made up primarily of water (75%), the ability of the muscle to retain this water post mortem (water-holding capacity) plays a significant role in the meat quality of the final product (Huff-Lonergan & Lonergan, 2005). The presence of fluid in the packaging of fresh meat is seen as a negative meat quality feature by consumers and consequently decreases consumer acceptance of a particular product (Troy & Kerry, 2010). For producers to control this, it's important to know the drip loss percentage (the amount of water exerted from the meat when a minimum force is applied) of the meat (Hutchison, Mulley, Wiklund & Flesch, 2012). There was a significant difference in drip loss of the different muscles mainly attributed to difference in fibre composition, myofibrils and spaces between filaments as determined by their physiological location and specialised function (Honikel, 1998). The drip loss measured in this study ranged from 0.9% in the forequarter (IS and SS) muscles and 1.6% in the SM. The 1.5% drip loss of the LTL was similar to the 1.6% reported for the same muscle in Chapter 3. This is considerably lower than that reported in previous studies on blue wildebeest LTL, (4.05%; Hoffman *et al.*, (2011)). This difference may be attributed to the higher muscle pH_U , although other factors such as cooling rate are also known to influence the water binding capacity in meat (Cheng & Sun, 2008).

A significant difference in cooking loss between the different muscle types was also observed. The highest cooking loss was observed in the ST (~40%) and the lowest in the IS (~31%). Similar findings were reported in Chapter 4 with the highest cooking loss being observed in the ST (~40%) and the lowest in the IS (~31%). For the LTL muscle a cooking loss of ~35% was recorded, which is higher than that reported for impala (*Aepyceros melampus*; ~31%) and kudu (*Tragelaphus strepsiceros*; ~32%) (Hoffman, Mostert, Kidd & Laubscher, 2009), but lower than that for blue wildebeest males (~39%) in an earlier study (Hoffman *et al.*, 2011).

Tenderness is regarded as the most important physical eating quality attribute as it determines consumer acceptability (Erasmus & Webb, 2014). In beef, Warner Bratzler shear force values < 42.8 N is considered tender while values > 52.68 N are considered to be associated with tough meat (Destefanis *et al.*, 2008). In this study there was a significant difference ($p = 0.0002$) in tenderness between the different muscle types (Table 7.5), attributed to the difference in muscle fibre composition, structure of the connective tissue, amount of intramuscular fat and presence of muscle shortening and enzymes associated with post-mortem tenderising (Swatland, 1994; Lawrie & Ledward, 2006; Hoffman, Kroucamp & Manley, 2007; Destefanis *et al.*, 2008; North, Frylinck & Hoffman, 2015). In this study the highest shear force value measured was ~36 N in the SM and the lowest ~21 N in the IS. Thus all the muscles in the study can be considered to be tender, with the latter being the most tender. Similar findings were recorded in Chapter 3, the SM being associated with the higher shear force values and the forequarter (IS and SS) muscles, the lowest.

As tenderness is the most important eating quality, so colour of the meat is an important visual quality as the appearance influences the initial selection for purchase by consumers (Geay *et al.*, 2001). Consumers prefer meat that is red and bright as it is perceived as fresh, while dark and pale meat is perceived as aged and unacceptable (Priolo *et al.*, 2001). Game meat is generally darker than meat from domestic livestock due to a higher myoglobin content, as muscles from game species are subjected to higher activity loads (Daszkiewicz *et al.*, 2012). Volpelli *et al.* (2003) reported that the dark colour associated with game meat that is attractive to consumers is characterised by an L^* value <40, a high a^* and a low b^* value. In this study all the different muscles had L^* values <40, ranging from ~35 in the ST to ~30 in the SS (Table 7.6). The former being lighter in colour than the latter. However, the opposite was seen in Chapter 3, where the highest L^* value was observed in the LTL, SM, IS and SS and lowest in the ST and BF, although the values all ranged from ~34 to 31; values intermediate to that reported in these blue wildebeest bulls. There was also high a^* values measured in the different muscle types with the highest values being associated with the forequarter (IS and SS) muscles, with the similar trend being seen in the Chroma values. It can therefore be concluded that the forequarter muscles have a more saturated red colour since the a^* value is positively correlated to the myoglobin concentration of the meat and the Chroma value is associated with the saturation/intensity of the colour (Vestergaard *et al.*, 2000).

The different muscle types had a low b^* value which is known to produce a colour that is attractive to consumers (Volpelli *et al.*, 2003). The highest b^* value was measured in the SM (~10) and ST (~9), values similar to that in Chapter 3. Therefore these muscles are associated with a more yellow/brown colour compared to the other muscle types, the forequarter muscles having the lowest b^* values, as the b^* value is related to the myoglobin structure rather than the myoglobin concentration, the latter being more closely correlated to the a^* value (Mancini & Hunt, 2005). As expected, a similar trend was observed for the hue-angle measured.

Meat from mammals are considered to be a valuable source of food because it typically consists of 75% water, 19% protein, 2.5% intramuscular fat (IMF) and 3.5% soluble non-protein constituents such as carbohydrates, minerals and vitamins (Huff-Lonergan & Lonergan, 2005; Olsson & Pickova, 2005; Lawrie & Ledward, 2006). Therefore the nutritional value and quality of meat is primarily defined by its basic chemical composition consisting of total moisture, protein, IMF and ash content, as it accounts for nearly 100% of the weight of animal tissue (Ang *et al.*, 1984). In the current study it was found that there was a significant difference ($p \leq 0.05$) between the different muscle types for moisture, protein and IMF content, with no significant difference in the ash content (Table 7.7).

Moisture content was highest in the SS (~78%), while the lowest was observed in the LTL (~75%). A similar trend was observed in Chapter 5 and by Fitzhenry (2016) for wild fallow deer (*Dama dama*) in South Africa. When compared to previous studies on blue wildebeest LTL muscles, a similar moisture content of ~76% has been reported (Hoffman *et al.*, 2011)

A close inverse relationship between moisture content and the levels of IMF in mammalian muscles has been reported (Sebranek, 2014; Young *et al.*, 2001). However this trend was not observed in this study as the highest IMF content was also observed in the forequarter (IS and SS) muscles. This could be attributed to the overall low fat content associated with game species that could have influenced the cumulative effect of the percentages, additionally IMF has also been shown to be the most variable of all the proximate components (Onyango *et al.*, 1997; Van Schalkwyk & Hoffman, 2010; Hocquette *et al.*, 2010; Hoffman & Cawthorn, 2012; Sebranek, 2014). The IMF content ranged from 1.3 - 2.2%, agreeing with the notion that game meat contains less than 3% IMF. Therefore the findings of this study is comparable to previous studies on blue wildebeest (~1.1%, Hoffman *et al.*, 2011), as well as to other game meat studies, namely kudu (~1.5 - 1.6%, Mostert & Hoffman, 2007; Hoffman *et al.*, 2009), impala (~2.1%, Hoffman *et al.*, 2009) and the common duiker (*Sylvicapra grimmia*) (~2.1%, Hoffman & Ferreira, 2004) as well as being comparable to livestock species such as pork muscle when the subcutaneous fat has been removed (~2.1%, Kim *et al.*, 2008).

This was expected as a close relationship between moisture content and the levels of protein have been identified in previous studies. It has been found that when there is an increase in moisture content it is related to a decrease in the levels of protein. This is because changes in the

various proteins molecules bind to water (when pH is above its iso-electric effect) however when these protein are denatured they lose their charge and decrease the binding to water, increasing the release of water from between the proteins causing an accumulation of moisture between the muscle fibres (Sebranek, 2014).

A close relationship between moisture and protein has been noted where an increase in moisture is associated with a decrease in protein (Sebranek, 2014). This is because when proteins are disrupted there is an increase in release of water (that was previously bound to the proteins) due to loss in protein surface charges causing an accumulation of moisture between the muscle fibres (Sebranek, 2014). This trend was confirmed with the highest protein content being observed in the LTL ($22.9 \pm 0.31\%$) and SM ($22.5 \pm 0.48\%$) and consequently the lowest moisture content also being observed in these muscles. This correlation was observed in Chapter 5. The protein content of the muscles ranged from 20.4 to 22.9% (Table 7.7) which exceeds the protein content considered to be found in mammalian muscles (19%), confirming that game meat has a higher protein content than meat derived from mammals such as livestock species (Jansen Van Rensburg, 2002; Lawrie & Ledward, 2006). These results are comparable to other blue wildebeest studies ($\sim 22.3\%$, Hoffman *et al.*, 2011) and to other African antelope species, namely gemsbok (*Oryx gazella*, 20.3%, Onyango *et al.*, 1997) and black wildebeest ($\sim 20.5\%$, Hoffman, Van Schalkwyk & Muller, 2009).

The concentration of salty and inorganic constituents did not differ between the different muscle types as shown by the measured ash content. The ash content of the current study was 1.1% for all the muscles, which is considerably lower than previously found for blue wildebeest ($\sim 2.4\%$, Hoffman *et al.*, 2011) but comparable to the results of Chapter 5, and that of other African antelope species, namely gemsbok (1.1%, Onyango *et al.*, 1997) and kudu ($\sim 1.2\%$, Mostert & Hoffman, 2007), as well as livestock species such as cattle ($\sim 1.0\%$, Moreira, *et al.* 2003).

7.5. CONCLUSION

This study has given reliable data that supports the production of quality meat from blue wildebeest bulls aged 28 months. These bulls have a higher dressing percentage than conventional livestock species, produces a mean of 125.4 kg carcass and 58 kg offal that can be utilised efficiently as a low cost protein and micronutrient source. The study highlighted that there are differences in meat quality between the different muscle types. Therefore in order to ensure consistent quality, each muscle should be utilised individually rather than marketing traditional-muscles cuts. The forequarter muscles (IS and SS) were found to be desirable with regards to drip loss, cooking loss, tenderness and intense bright red colour in comparison to the hindquarter muscles. However all six muscles studied were within the range for the different physical parameters that are considered to be associated with good quality meat. For the chemical analyses it was found that the hindquarter muscles had a more nutritionally desirable composition, having a lower moisture content, higher protein content and lower IMF fat content than the forequarter muscles. However all six muscles

studied produced values that confirm that game meat is a lean and healthy alternative red meat source to conventional livestock red meat such as lamb and beef. From this study it can be concluded that animals farmed in a semi-extensive production system produced meat of good quality.

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CHAPTER 8

LENGTH OF AGING TO ACHIEVE THE MOST TENDER BLUE WILDEBEEST (*Connochaetes taurinus*) STEAK

ABSTRACT

This study determined the optimum aging period for vacuum-packed blue wildebeest *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) muscles, obtained from bulls of similar ages (28 months) and feeding level. The muscles were obtained from eight blue wildebeest bulls, portioned and aged for 2, 5, 9, 14, 20 and 28 days at 4°C. The Warner Bratzler shear force trend showed a decreased within the first 9 and 14 days of aging for the LTL and BF muscles, respectively where after it plateaued. This decline in tenderness was associated with an increase in cumulative purge loss that also plateaued after day 9. There was no change in the cooking loss throughout the aging period. The LTL muscle had significantly lower WBSF, higher purge loss and lower cooking loss than the BF. Throughout the aging period, both muscle types delivered the colour characteristics typical of game meat with L* values <40, high a* and low b* values, with the LTL muscle measuring lower a* and Chroma values than the BF. Both muscles also obtained proximate nutritional values associated with lean and healthy meat, with the LTL having a lower moisture but higher protein content than the BF. This study found that to achieve optimum tenderness vacuum packed blue wildebeest LTL muscles should be aged for nine days and BF muscles for 14 days at 4°C.

Keywords: Game meat, Blue wildebeest, Aging, Tenderness

8.1. INTRODUCTION

Game meat consumption in Africa is an age-old practice and is an alternative protein source to beef in many regions (Onyango, Izumimoto & Kutimaa, 1998). With the growth of the game industry in South Africa there has been a 40-fold increase in the number of game species found on privately owned land since 1960 (Taylor, Lindsey & Davies-Mostert, 2016). This is because game species are able to thrive in the semi-arid regions of South Africa, where livestock production is currently struggling to adapt to the increased occurrence of extreme environmental conditions brought about by global warming while game species are adapted, physiologically, to survive in these conditions while still remaining highly productive (Cole, 1990; McMichael, Woodruff & Hales, 2006; Hoffman & Cawthorn, 2012). Therefore producing meat from game species is an important aspect that should be researched to increase meat production and consumption and counteract the food security challenge.

The meat industry is currently consumer driven with demands for healthy food products that have the desirable nutritional composition (Radder & Le Roux, 2005). Fortunately previous studies highlight that game meat is low in fat, high in protein and high in iron, while also being both free-range and organic (Hoffman *et al.*, 2005; Hoffman & Wiklund, 2006). Consumers are also demanding products of consistent high quality (Hutchison, Mulley, Wiklund & Flesch, 2010). Therefore in order for a product to become a standard addition to supermarket shelves it is important that all the previously mentioned factors are adhered to by producers.

The eating quality of meat is most commonly described as a combination of flavour, juiciness and tenderness (Strydom *et al.*, 2016). With consumers showing the most dissatisfaction to inconsistent tenderness in comparison to other meat quality attributes (Brooks *et al.*, 2000). As shown by Miller, Ramsey, Hoover, Carr & Crockett (2001), who found that with an increase in shear force of steaks from 22.17 N to 36.21 N, consumer acceptability decreased from 100% to 25%. The factors that contribute to the toughness of meat can be divided into those making up connective tissue (mainly total and insoluble collagen) and those that make up the structural components of meat (the myofibrillar, cytoskeletal and sarcoplasmic proteins) (Koohmaraie, Kent, Shackelford, Veiseth & Wheeler, 2002; Purslow, 2005). The collagen content determines the background toughness of meat when measured using the Warner Bratzler shear force, while the remaining structural proteins additively act together causing variation in the toughness of meat beyond that contributed by connective tissue (Koohmaraie *et al.*, 2002; Sentandreu *et al.*, 2002; Purslow, 2005). It is however doubtful that any significant differences exist in the collagen solubility of muscles from animals of similar age, therefore difference or variation in tenderness of animals of the same age is attributed to the difference in myofibrillar protein degradation and not collagen solubility (Koohmaraie, 1994).

Tenderness is the most critical eating quality (organoleptic characteristic) that is sought after by the modern consumer (Erasmus & Webb, 2014). There are several misconceptions surrounding the tenderness of game meat or the lack thereof (Hoffman, Muller, Schutte & Crafford, 2004). Therefore the study of this meat quality attribute is essential to increase consumer awareness and optimize processing. Aging of meat by storing it at refrigerated temperatures for a period of time, is a process that has been used for decades to improve meat texture in terms of tenderness (Dransfield, 1994). This is because when a carcass or muscle is stored post mortem proteins are broken down by endogenous proteinases resulting in numerous changes in the micro and ultrastructure of muscle fibres within the skeletal muscle that results in loss of tissue integrity, translating into the observed improvement of meat tenderness during aging (Koochmaraie, 1994; Nowak, 2011).

This process is however very variable, depending on a number of biological factors such as species, age, sex, muscle type, temperature and duration of storage (Dransfield, 1994). Increasing the tenderness through aging is unfortunately also associated with changes in colour, aroma and flavour, which usually with increased aging is associated with undesirable changes (Stetzer *et al.*, 2008). This is caused by chemical changes that occur during aging including protein and lipid oxidation and the denaturation and degradation of proteins (Campo *et al.*, 1999). Therefore it is necessary to develop the correct handling and processing protocols for each game species, rather than referring to pre-existing standards from beef or sheep industries (North *et al.*, 2015).

Often aging is also associated with loss of moisture during storage in the form of purge/weep loss from the meat which can be an undesirable effect if it occurs in excess, due to loss in mass but also an accumulation of fluid in the packaging which is detrimental to the product appearance and influences consumer-purchasing decisions (Troy & Kerry, 2010). The amount of water retained in meat before and after cooking influences its juiciness and consequently its palatability (Strydom *et al.*, 2016). Therefore the loss of water from meat during storage and during cooking through evaporation is an important aspect to consider when aging meat (Aaslyng, Bejerholm, Ertbjerg, Bertram & Andersen, 2003).

Blue wildebeest (*Connochaetes taurinus*) is one of the larger bushveld ungulate species found in South Africa and has become a popular addition to all forms of game farming (Furstenburg, 2002). These animals are hardy, highly adaptable and widely distributed in South Africa with an annual population increase of 29 to 35% (Furstenburg, 2002). In many cases the primary aim of farming this species is to breed golden wildebeest (*Gnu*) or to produce animals of high-quality for live sale or trophy hunting. However in order to produce animals of perfect health and optimum condition, good management practises are essential. This often includes the regular culling of surplus or sub-standard stock and thus the production of game meat (Bezuidenhout, 2012). Blue wildebeest could therefore be considered as a viable complementary or alternative source of animal protein. Traditionally, game meat was predominately processed into biltong (Jones, Arnaud, Gouws

& Hoffman, 2017). However as the industry developed and these surplus animals became available, linked to the increase in tourists visiting South Africa and their wish to have an “African experience”, a market has opened for the sale of quality game meat in restaurants frequented by tourists (Hoffman, Crafford, Muller & Schutte, 2003; Taylor *et al.*, 2016). As mentioned, consumers expect quality (tender) meat, yet very little information exists on the conditions (e.g., length of aging) required to ensure a “tender” steak.

The aim of this study was thus to determine the optimum aging period for vacuum-packed blue wildebeest meat from two muscles that form part of the high-value cuts, *Longissimus thoracis et lumborum* and the *Biceps femoris* muscles, obtained from animals of similar ages and feeding level. This methodology (wet aging) of aging meat, in comparison to aging the whole carcass, has become increasingly popular as it saves costs of aging (refrigeration space, etc.) and decreases this risk of microbial growth (Hodges, Cahill & Ockerman, 1974; Buys, Nortjé & Van Rensburg, 1997).

8.2. MATERIALS AND METHODS

8.2.1. Animals and location

A total of eight blue wildebeest (*Connochaetes taurinus*) bulls (age 28 months) were selectively harvested from a herd of 300 bulls that has been selected for culling as their horns did not reach the required minimum that was acceptable for stud breeding. However, there was no indication that their carcasses were inferior to that of the breeding stud bulls.

The semi-extensive farming system (Sandstone valley S 24°33,764' – E026°02,510') was situated in the Modimolle region in Limpopo province, South Africa. This location falls within the Central Sandy Bushveld veld type that is characterised by gentle sloping hills and hallows found between mountains and sandy plains with tall woodland trees. It has a grass-dominating herbaceous layer with relatively low basal cover on dystrophic sands (Mucina & Rutherford, 2006). The animals ($n=300$) were permanently maintained in a breeding camp of 600 ha and received a daily 3 kg/animal ration of strategic supplementary feed. The formulation of the supplementary feed (mixed using a on-farm mixer to form a homogenous ration) at point of harvest was: grass (33.99%), maize (15.69%), Brewers grain (12.5%), molasses (12.55%), soya oil cake (7.32%), wheat (6.24%), cotton oil cake (5.23%), Lucerne (3.92%), lime (0.94%), phosphate trace-mineral supplement - high in monocalcium phosphate - (0.94%), mineral premix (0.34%), and salt (0.26%). This typical diet varies with regards to availability of the main ingredients. The two farms were approximately 45 km from each other.

8.2.2. Culling and dressing

The animals were culled during the day using a 0.308 calibre rifle with a sound suppressor by a marksman on the back of a secure hunting vehicle, to minimise the stress of the animals. All

procedures performed during culling, slaughtering and dressing were done as according to Van Schalkwyk & Hoffman (2016).

Refer to Material and Methods of Chapter 3.2.2, for more detailed information.

8.2.3. Sample preparation

After ~48 hours of cooling, from both sides of the carcass, the hind limb muscle *Biceps femoris* (BF) and the loin muscle *Longissimus thoracis et lumborum* (LTL) were removed. The BF was removed in its totality and the LTL removed from between the last lumbar vertebra and the natural termination of the muscle at the cervical vertebra. Each muscle (right and left side) was cut perpendicular to the longitudinal axis of the muscle to give approximately three equal portions [~660 g (LTL) and ~775 g (BF)], resulting in six portions per muscle type. Each portion was then randomly allocated (based on a randomisation function run on excel) to be analysed on the various aging trial days: 2, 5, 9, 14, 20 and 28 (Table 8.1). Day 0 was taken as the day the animals were harvested. The animal's dressed carcass was then left to hang in a cool room for 48 hours, and muscles removed on day 2. The steak allocated to day 2 was divided in two, while the cranial part of the steak underwent physical analyses immediately, while the caudal part of the steak was kept for chemical analyses and stored at $-2.6 \pm 0.07^{\circ}\text{C}$ under vacuum until reaching Stellenbosch University laboratory where it was frozen at -20°C until analysis.

The rest of the aging samples were weighed, vacuum packed and stored at 4°C until physical analyses. At the end of each aging period the portions were removed from the vacuum packaging and subjected to the selected physical analyses.

Table 8.1 Summary of the experimental layout of the trial per main effect (muscle type and ageing period).

Number of animals	Muscle	Ageing periods (days post-mortem)					
		2	5	9	14	20	28
8	LTL	2	5	9	14	20	28
8	BF	2	5	9	14	20	28

Abbreviations: LTL = *Longissimus thoracis et lumborum*, BF = *Biceps femoris*

8.2.4. Physical analyses

8.2.4.1. Acidity (pH)

The pH was determined at each aging period. For each muscle portion the pH was determined in the centre of the portion. The pH was measured using a calibrated portable Crison pH25 pH meter with a glass electrode (pH standard buffers at pH 4.0 and pH 7.0). The electrode was washed clean with distilled water between measurements.

8.2.4.2. *Moisture loss*

Moisture loss was measured using two processes: cumulative purge loss in raw meat during storage and moisture loss in cooked meat. Cumulative purge loss was measured by weighing the portions prior to vacuum-packaging (day 2) to determine their initial mass. The portions were then subsequently weighed at the completion of aging after being blotted dry with an absorbent paper towel to determine moisture loss during aging (also known as weep). This moisture loss was expressed as a percentage of the initial mass of each portion.

Cooking loss percentage was measured at the end of each aging period after portions had been cut perpendicularly to the direction of the muscle fibres to produce three steaks of ~1.5 cm (~150 g) thick. The steaks were weighed individually before being placed into a plastic bag that was subsequently submerged into a preheated water bath (maintained at 80°C) for 60 min. Steaks were then removed and allowed to cool overnight in a refrigerator at 4°C. Once cooled, the samples were removed from the plastic bag, blotted dry using absorbent paper to remove excess moisture and weighed. Cooking percentage was calculated by determining the difference between the raw mass and cooked mass and expressed as percentage of raw mass (Honikel 1998).

8.2.4.3. *Warner Bratzler shear force (WBSF)*

Subsequent to the cooking loss measurement, the cooked samples were used to determine the tenderness of the meat. Six 1.27 cm diameter cylindrical cores (from the centre of the sample, care being taken to exclude any visible collagen tissue) were removed and sheared perpendicular to the fibres longitudinal orientation with a Warner Brazler blade (circular cross section of 1.27 cm Φ), moving at a cross speed of 3.33 mm/s and fitted to an electrical scale to measure maximum weight (force), recorded in kg/1.27cm Φ . The average of the six readings was calculated and the value used to describe the tenderness of the particular muscle, with a greater force being associated with tougher meat (Honikel, 1998). The calculated average in kg/1.27cm Φ was then converted into newton (N) to maintain a consistent unit used throughout the thesis and for comparison with other reported values from previous studies. Conversion was as follows:

$$\text{Shear force (N)} = \text{kg} \cdot 1.27 \text{ cm} \cdot 9.81 / \text{Area}$$

$$\text{Where area} = \pi (1.27/2)^2$$

8.2.4.4. *Surface colour*

The colour of the fresh meat was determined on the three ~1.5 cm thick steaks cut perpendicularly to the direction of the muscle fibres. The steaks were left to bloom for ~30 minutes where after the colour coordinates were measured on five random locations on the surface of the cut meat using a Colour-guide 45°/0° colorimeter (BYK-Gardner GmbH, Gerestried, Germany), according to the CIE L*a*b* colour system (Honikel, 1998). This system reported coordinates measuring CIE L*

(lightness), CIE a^* (green-red value) and CIE b^* (blue-yellow value). Chroma value (saturation/colour intensity) and hue-angle (colour definition) was then calculated using the CIE a^* and CIE b^* values as follows:

$$\text{Chroma value (C}^*) = (a^{*2} + b^{*2})^{0.5}$$

$$\text{Hue-angle (}^\circ) = \tan^{-1}(b^*/a^*)$$

8.2.5. Chemical analyses

The samples were prepared and the proximate analysis performed as explained in the Materials and Methods of Chapter 5.3.4.

8.2.6. Statistical analyses

The trial was designed as a randomised block split plot design. Animal was considered as block replicates for the main plot factor muscle and ageing period (days post mortem (PM)) as the split plot factor (each muscle divided into portions to be evaluated over time) and all effects tested using the appropriate error term. Therefore the model is described as follows:

$$y_{ijk} = \mu + g_i + m_j + gm_{ij} + a_k + ma_{jk} + \varepsilon_{ijk}$$

Where the terms within the model are defined as (μ) the overall mean, (g_i) the effect of animal, (m_j) the effect of muscle, (gm_{ij}) the error term for the main plot factors (g_i) and (m_j), (a_k) the effect of the ageing period, (ma_{jk}) the muscle by ageing period interaction, and (ε) the error term for the subplot factor and interactions.

The statistical analyses were performed using SAS software (Version 9.4; SAS Institute Inc., Cary, USA). A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). Where there was significant deviation from normality, such when the standardised residual for an observation deviated with more than three standard deviations from the model value, outliers were evaluated and where applicable, removed. To determine whether there was differences between the treatments, a univariate analysis of variance (ANOVA) using General Linear Models (GLM) procedures were performed. To compare the means, a Fisher's t-least significant difference was calculated (Ott, 1998). A 5% probability level was considered significant for all tests testing significance. The values are reported as the Least Square Means and standard error.

8.3. RESULTS

8.3.1. Physical analyses

No significant interactions between the main effects, muscle and day post mortem (PM), were present for any of the physical parameters measured. Thus the main effects will be discussed separately.

There was no difference between the two muscles types for pH (Table 8.2). There was a change in pH during aging, with a significant day effect ($p < 0.0001$), with a linear decreasing trend found with the increase in aging period ($p < 0.0001$), Table 8.2.

A significant difference ($p = 0.037$) was observed between the muscles for cumulative purge loss, with the LTL having a higher level of moisture loss than the BF (Table 8.2 and Fig. 8.1, respectively). There was also a significant day effect ($p = 0.004$) where the purge loss increased in a linear manner from day 2 to day 9, at which point it plateaued, with no significant difference present between day 9 and day 28 (Table 8.2), this same increasing trend was observed for both muscle types (Fig. 8.1).

The BF had higher ($p = 0.024$) levels of cooking loss than the LTL (Table 8.2 and Fig. 8.2, respectively), with aging period having no effect on the cooking loss during the six different aging periods (Table 8.2).

For Warner Bratzler shear force (WBSF) measured in both kg/1.27cm Φ and N, a difference between muscle type and aging period was seen (Table 8.2). The BF was significantly tougher than the LTL, as indicated by higher shear force values (~ 6 N) (Fig. 8.3), with an estimated trend ($p = 0.006$) of a decline in shear force values with increasing storage duration with a more consistent trend observed in the LTL than the BF. For the LTL there was a significant ($p \leq 0.05$) decline in WBSF values to day 9 after which it plateaued, while a decrease in shear force was noted for BF throughout the aging period with the lowest value being reached on day 14, however not significantly differing from the other values (Fig. 8.3). There was a significant day effect ($p = 0.004$, Table 8.2), with a decline in shear force between day 2 and day 14, with day 9 to day 28 not differing significantly in tenderness. This indicates that no further changes in tenderness occurred after 9 days of aging.

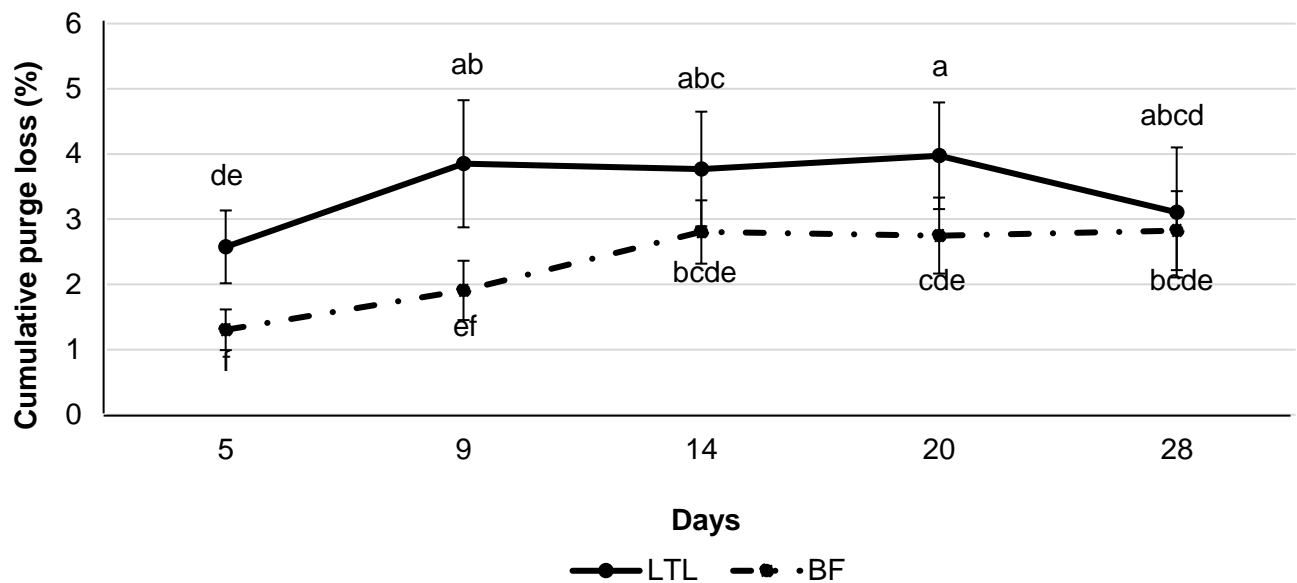


Figure 8.1 The change in cumulative purge loss of blue wildebeest muscles, *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) during aging up to 28 days post mortem. Different letters indicate significant differences ($p \leq 0.05$) between mean values. Error bars indicate standard error of the mean of each group.

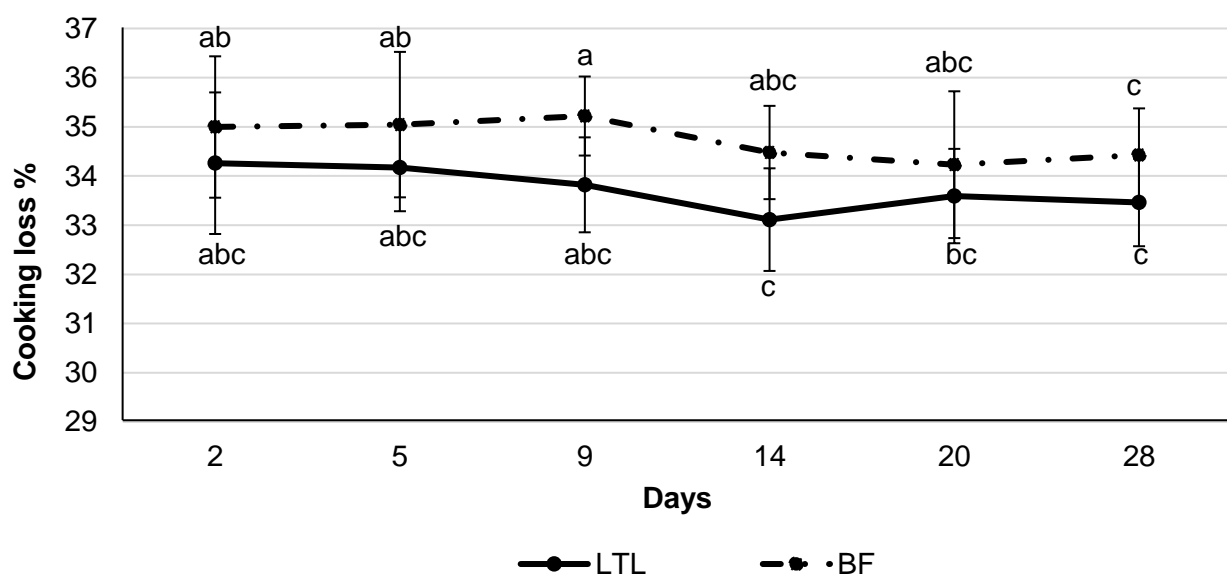


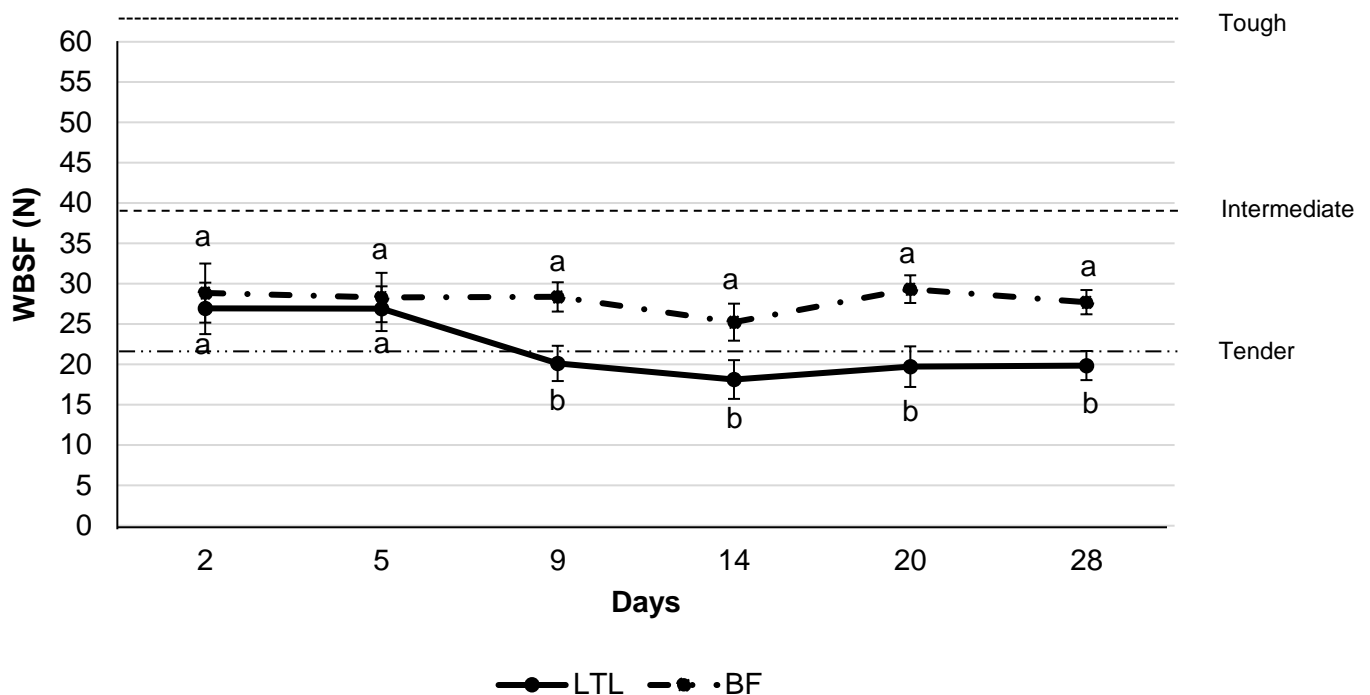
Figure 8.2 The change in cooking loss of blue wildebeest muscles, *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) during aging up to 28 days post mortem. Different letters indicate significant differences ($p \leq 0.05$) between mean values. Error bars indicate standard error of the mean of each group.

Table 8.2 Blue wildebeest muscle pH, cumulative purge loss, cooking loss and Warner Bratzler shear force as per muscle and ageing period (LSMean \pm standard error). Significant differences are highlight in bold ($p \leq 0.05$).

	Muscle		p-value	Aging period (days PM)						p-value
	LTL	BF		2	5	9	14	20	28	
pH	5.8 \pm 0.05	5.8 \pm 0.05	0.675	5.9^{bc} \pm 0.08	6.0^a \pm 0.11	5.9^{ab} \pm 0.10	5.8^c \pm 0.09	5.7^d \pm 0.12	5.6^d \pm 0.09	<.0001
Cumulative purge loss (%)	3.5 \pm 0.34	2.3 \pm 0.21	0.037		1.9^b \pm 0.35	2.9^a \pm 0.58	3.3^a \pm 0.50	3.4^a \pm 0.51	3.0^a \pm 0.56	0.004
Cooking loss %	33.7 \pm 0.38	34.7 \pm 0.43	0.024	34.6 \pm 1.0	34.6 \pm 0.84	34.5 \pm 0.63	33.8 \pm 0.70	33.9 \pm 0.86	33.9 \pm 0.64	0.394
WBSF (kg/1.27cm Φ)	2.8 \pm 0.12	3.6 \pm 0.13	0.025	3.6^a \pm 0.30	3.6^{ab} \pm 0.26	3.2^{bc} \pm 0.22	2.8^c \pm 0.24	3.1^{abc} \pm 0.25	3.1^c \pm 0.20	0.004
WBSF (N)	21.9 \pm 1.01	28.0 \pm 0.90	0.025	27.9^a \pm 2.36	27.6^{ab} \pm 2.00	24.2^{bc} \pm 1.74	21.7^c \pm 1.85	24.5^{abc} \pm 1.92	23.8^c \pm 1.52	0.004

Abbreviations: LTL = *Longissimus thoracis et lumborum*, BF = *Biceps femoris*, WBSF = Warner Bratzler Shear Force.

^{a-c} Row means with different superscripts differ significantly at $p \leq 0.05$.



D

Figure 8.3 The change in the Warner Bratzler shear force (N) of blue wildebeest muscles *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) during aging up to 28 days post mortem. Different letters indicate significant differences ($p \leq 0.05$) between mean values. Error bars indicate standard error of the mean of each group. The tenderness categories are adapted from Miller, Ramsey, Hoover, Carr, & Crockett, (2001).

For the colour measurements, there was a significant muscle effect observed for both a^* and Chroma values. Higher ($p = 0.011$) a^* values were seen in the BF than the LTL (Table 8.2 & Fig. 8.4, respectively), with the similar trend measured for the Chroma value (Table 8.2 & Fig. 8.5, respectively), with BF measuring a higher ($p = 0.031$) Chroma value than the LTL muscle. There was also a significant day effect ($p < .0001$) for both these colour parameters with a quadratic increase in values with increasing aging days with day 20 and 28 not differing significantly (Table 8.3).

In addition, aging day also had an effect on all the remaining colour parameters measured ($p \leq 0.05$, Table 8.3). The L^* value increased quadratically with the increase in aging day by increasing steadily until day 20, after which it decreased at day 28. For the b^* values there was a steady increase until day 14 after which it reach a plateau until day 28, with no differences being present between day 14 and day 28. The change between the hue-angle during aging was linear ($p = 0.002$), with values increasing after day 7 until day 28.

Table 8.3 Blue wildebeest muscle colour parameters as per muscle and ageing period (LSMean \pm standard error).

	Muscle		p-value	Ageing period (days PM)						p-value
	LTL	BF		2	5	9	14	20	28	
L*	32.1 \pm 0.4	32.5 \pm 0.35	0.467	31.9 ^b \pm 0.61	31.9 ^b \pm 0.66	32.3 ^b \pm 0.76	32.5 ^{ab} \pm 0.76	33.12 ^a \pm 0.77	32.1 ^b \pm 0.69	0.022
a*	13.8 \pm 0.37	14.7 \pm 0.35	0.011	12.3 ^d \pm 0.38	12.8 ^d \pm 0.44	14.1 ^c \pm 0.56	15.1 ^b \pm 0.72	15.9 ^a \pm 0.77	15.4 ^{ab} \pm 0.66	<.0001
b*	9.1 \pm 0.39	9.8 \pm 0.34	0.130	8.1 ^c \pm 0.41	7.7 ^c \pm 0.51	9.2 ^b \pm 0.73	10.4 ^a \pm 0.72	10.8 ^a \pm 0.71	10.8 ^a \pm 0.53	<.0001
Chroma	16.6 \pm 0.52	17.7 \pm 0.46	0.031	14.8 ^d \pm 0.51	15.0 ^d \pm 0.63	16.9 ^c \pm 0.84	18.3 ^b \pm 0.97	19.2 ^a \pm 1.03	18.8 ^{ab} \pm 0.82	<.0001
Hue-angle	32.8 \pm 0.59	33.2 \pm 0.52	0.573	32.8 ^b \pm 2.14	30.4 ^c \pm 1.03	32.3 ^{bc} \pm 1.26	34.1 ^{ab} \pm 0.94	33.7 ^{ab} \pm 0.74	34.8 ^a \pm 0.69	0.0003

Abbreviations: LTL = *Longissimus thoracis et lumborum*; BF = *Biceps femoris*^{a-c} Row means within aging period with different superscripts differ significantly at $p \leq 0.05$.

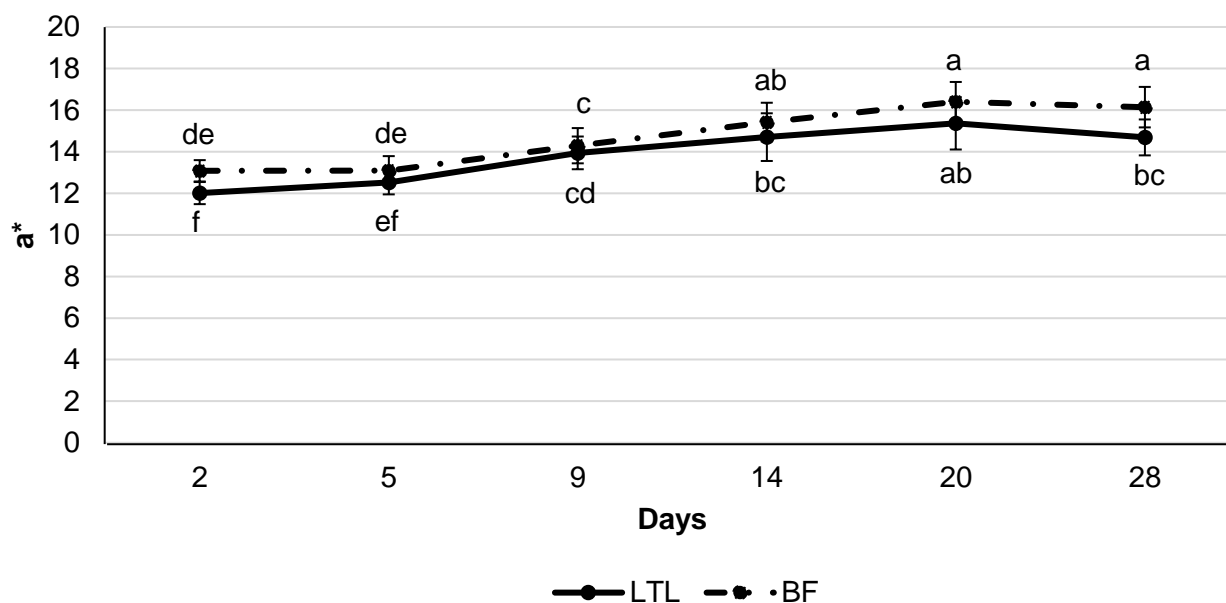


Figure 8.4 The change in the a^* colour co-ordinate of blue wildebeest muscles, *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) during aging up to 28 days post mortem. Different letters indicate significant differences ($p \leq 0.05$) between mean values. Error bars indicate standard error of the mean of each group.

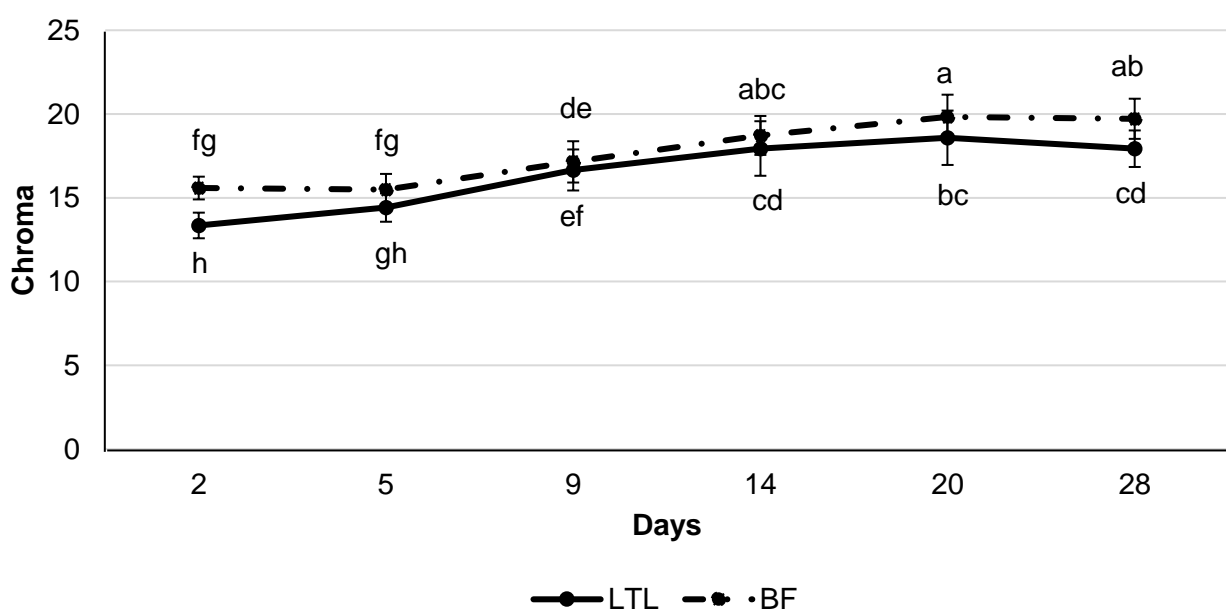


Figure 8.5 The change in the hue-angle colour co-ordinate of blue wildebeest muscles, *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) during aging up to 28 days post mortem. Different letters indicate significant differences ($p \leq 0.05$) between mean values. Error bars indicate standard error of the mean of each group.

8.3.2. Chemical analyses

The proximate results of the two muscles are presented in Table 8.4. There was a significant difference ($p \leq 0.05$) in the moisture and protein content between the muscles, however no significant difference in the intramuscular fat (IMF) and ash content was noted. A higher moisture content was found in the BF compared to the LTL, with the LTL having a higher protein content than the BF.

Table 8.4 Proximate analysis (%) of two selected blue wildebeest muscles. Values given as LSMeans (\pm standard error).

Parameter	Muscle type		p-value
	LTL	BF	
Moisture	75.4 \pm 0.36	76.5 \pm 0.37	0.023
Protein	22.9 \pm 0.31	21.4 \pm 0.31	0.007
IMF	1.5 \pm 0.13	1.8 \pm 0.22	0.233
Ash	1.1 \pm 0.03	1.1 \pm 0.02	0.663

Abbreviations: LTL = *Longissimus thoracis et lumborum*; BF = *Biceps femoris*, IMF = Intramuscular fat.

8.4. DISCUSSION

As seen in Figure 8.4, there was little change in the shear force values of blue wildebeest meat past day nine of aging with the lowest values being observed at day 14 of aging. It has been found that the same plateau in tenderisation is observed after 11 to 14 days of aging in beef (Smith, Culp & Carpenter, 1978; Koohmaraie, Whipple, Kretchmar, Crouse & Mersmann, 1991; Sentandreu *et al.*, 2002; Nowak, 2011), as well as in lamb after the first two weeks of aging (Coombs, Holman, Van De Ven, Friend & Hopkins, 2016). At 14 days post mortem aging, the LTL measured a shear force value of 18.1 N and the BF 25.2 N (Fig. 8.4). Thus the BF has significantly ($p = 0.025$) higher shear force values than the LTL throughout the ageing period, with BF values ranging from 25.2 to 28.8 N while values recorded for LTL ranged from 18.1 to 26.9 N. This corresponds with the findings by North *et al.* (2015) in aged springbok (*Antidorcas marsupialis*) meat, where the BF muscle was less tender than the LTL muscle, as well as with the National Beef Tenderness survey 2010/2011 which noted that round muscles are consistently less tender than other muscles (Guelker *et al.*, 2013). This is most likely as a result of the higher insoluble collagen found in the BF compared to the LTL, indicated by a higher total collagen and lower collagen solubility in the BF (Rhee, Wheeler, Shackelford & Koohmaraie, 2004; North *et al.*, 2015). Since soluble and insoluble collagen content in a muscle does not change with aging, the lack of improvement in BF WBSF values as seen in Figure 8.4 could be attributed to the large background toughness of the BF caused by high levels of insoluble collagen (Silva, Patarata & Martins, 1999; Sentandreu *et al.*, 2002; Colle *et al.*, 2015).

The rate of decline in shear force was higher in the LTL with a decline of 8.8 N in the first 14 days of aging compared to a low 3.6 N observed in the BF (Fig. 8.4). Previous studies have

shown that muscles with low connective tissue such as the LTL have a higher aging response in comparison to high connective tissue muscles such as the BF (Thompson, 2002). Thus the connective tissue in the BF contributes a larger portion of the structural integrity relative to the LTL, with the myofibrillar fraction being more susceptible to proteolytic degradation (Sentandreu *et al.*, 2002). Colle *et al.* (2015) found that tenderness scores for BF was greater when a product was aged for 21 days or longer compared to a product aged for 2 days as rated by a consumer panel, while WBSF values did not improve with aging. This is consistent with findings of Gruber *et al.* (2006) who found that WBSF values of BF muscles did not improve past day 21 post mortem. Colle *et al.* (2015) found that with the increase in the tenderness of BF muscle with ageing, the willingness to purchase BF steaks also increased from 53% after 2 days of aging to 63% after 14 days of aging and to 75% after 21 days of aging. This suggests that BF muscles should be aged for at least 14 days respectively to optimise consumer perception of tenderness. This is in accordance with the findings of the present study with the lowest shear force value being obtained at fourteen days of aging, with no significant changes observed after day 14.

The shear force of both muscles are considerably lower than that measured for beef where beef LTL has been recorded to range between 26.3 – 35.6 N and BF an average of 31.8 N at fourteen days of aging (Smith *et al.*, 1978; Koohmaraie *et al.*, 1991). This is to be expected as the shear force measured for non-aged (muscle removed 24 hours post mortem) blue wildebeest LTL was 37.8 ± 2.07 (Chapter 4), while beef has been recorded to be between 40 and 60 N (Crouse & Koohmaraie, 1990; Shackelford, Wheeler & Koohmaraie, 1997). This is consistent with findings of previous studies that have noted that meat from game animals is more tender than that from beef due to lower total collagen (Hutchison *et al.*, 2010; Bureš, Bartoň, Kotrba & Hakl, 2015). In this study the shear force for blue wildebeest meat aged from day 2 to day 14 saw a decline in 6.2 N which is less than has been recorded for beef at day 14 PM (10-16 N) (Crouse & Koohmaraie, 1990; Shackelford *et al.*, 1997). However, in the present study the aging trial began two days post mortem where if the initial shear force recorded 24 hours post mortem in Chapter 4 were to be used, a predicted decline of 16 N is expected at day 14 PM.

The rate of tenderisation in meat has been correlated to the activity of the proteolytic enzymes and the overall efficiency of these systems during aging (Nowak, 2011). It has been noted that the activity of these enzymes are higher in venison compared to that of beef and therefore venison should have a higher rate of tenderisation, resulting in a greater aging response (Koohmaraie *et al.*, 1991; Hutchison *et al.*, 2010). This is confirmed in the study with the tenderness plateau being reached as early as 9 days post mortem compared to 11 or 14 days recorded for beef as mentioned earlier. The comparison of the WBSF values to tenderness categories developed for beef further confirms the greater aging response, with all samples falling within the 'intermediate' category (with a 97% consumer acceptability as defined by Miller *et al.*, 2001) at the start of the aging period, whilst a 100% acceptability had been reached by day 14 PM. Thus the systems of key

myofibrillar proteins such as cathepsins, calpains and proteasomes are regarded as being responsible for a faster rate of post-mortem proteolysis in game meat rather than a restriction of tenderisation due to collagen content (Nowak, 2011).

Purge is the fluid loss in fresh meat and can be influenced by pH and myofibrillar spacing as water in meat is either bound to proteins, free water or entrapped by steric effects and/or attracted to bound water (Huff-Loneragan & Lonergan, 2005). The latter being most effected by the rigor process because of the decrease in muscle pH during this process caused by the anaerobic conversion of glycogen to lactic acid. This results in the net charge of proteins being reduced leading to the loss of water molecules' ability to bind and therefore water is able to escape from the muscle (Strydom *et al.*, 2016; Huff-Loneragan & Lonergan, 2005). However this most commonly happens when muscle pH reaches the iso-electric point of the main muscle proteins (myosin) which occurs at a pH of ~5.4. In the present study the pH declined from 5.9 ± 0.08 on day 2 to 5.6 ± 0.09 on day 28, therefore the pH remained above the iso-electric point of meat proteins, resulting in pH probably having a less prominent effect on water-holding capacity.

There was however an increase in pH from day 2 to day 5 followed by a decrease in the pH until day 28, which is in contrast to the findings of Wiklund, Dobbie, Stuart & Littlejohn (2010), who noted an increase in the pH of red deer (*Cervus elaphus*) meat during aging. While no change in the pH of cattle *Longissimus dorsi* (LD) aged for up to 6 days has also been reported by Ruiz de Huidobro, Miguel, Onega & Blázquez (2003). The initial increase in pH can be explained by the changes in the charge of the proteins due to the activity of proteolytic enzymes at the start of post mortem aging (Boakye & Mittal, 1993). While the decline in pH from day 9 to 28 may be attributed to the production of lactic acid by lactic acid bacteria which is favoured under anaerobic conditions (as in vacuum packed conditions) (Li, Babol, Wallby & Lundström, 2013).

It has been noted that a purge loss of 1 to 2% is acceptable where a purge loss greater than 4% would be excessive and have a negative impact on consumer perception and meat quality of the product (Colle *et al.*, 2015). In the current study the average purge loss for the BF was 2.3% while LTL had a mean purge loss of 3.5%. A maximum purge loss of 4.0% was reached after 20 days of aging, similar to that found for vacuum packed lamb LTL (Coombs *et al.*, 2016). The purge loss was expected to be higher than found in the industry because the whole sale cuts were divided into 6 sections for each of the 6 aging periods, thus increasing the surface area to volume ratio during storage. When the purge loss of the present study is compared to previous studies it is lower than values reported for vacuum-packed age springbok meat (North *et al.*, 2015), but higher than that reported for beef (Hodges *et al.*, 1974; Li *et al.*, 2013; Strydom *et al.*, 2016)

The purge loss started to plateau as early as day 9 of aging in the present study, with a decrease from day 20 to day 28 (Fig.8.2). This finding is in contrast to previous studies that have found that there was an increase in purge loss with an increase in storage time (Hodges *et al.*, 1974; Colle *et al.*, 2015).

A significant difference ($p = 0.037$) in purge loss was noted between the different muscle types, with LTL having a higher moisture loss throughout the ageing period compared to the BF. This is in contrast to previous studies that have shown that BF muscles are traditionally characterised by high purge loss (McKenna *et al.*, 2005). The findings of the current study are therefore attributed to differences in the size of the muscles, resulting in differences in the portions, with LTL portions having a greater cut surface area (Johnson, 1991). Another reason for less moisture loss from the BF during aging could be attributed to the more rapid proteolysis found in the BF resulting in a decrease in the movement of entrapped water out of muscle cells (Huff-Lonergan & Lonergan, 2005).

Despite differences in purge loss there was no difference in cooking loss observed throughout the aging period, a finding similar to that observed by Coombs *et al.* (2016) for aged lamb. The LTL had a higher purge loss but a lower cooking loss than the BF. Since the BF was recorded as being tougher than the LTL, attributed to having twice as much collagen than the LTL, it explains why the BF had a higher measured cooking loss than the LTL, as previous studies have linked collagen values to cooking loss, with muscles having higher cooking loss also having higher collagen values; it is thought that part of the higher loss is also caused by the physical shrinkage of the insoluble collagen during the heating process forcing the water molecules out of the meat matrix (Rhee *et al.*, 2004; Colle *et al.*, 2015). Also, insoluble collagen becomes more concentrated in steaks during cooking as it is not lost through cooking fluid, hence meat with higher cooking loss is also associated with higher WBSF values (Colle *et al.*, 2015). It also seems that the higher cooking loss found for the BF is linked to the lower purge loss for this muscle, as more moisture was available to be lost during the cooking process.

Meat colour is the main factor affecting meat product acceptability at the time of purchase, where its discolouration is the leading cause of lost retail sales (Geay *et al.*, 2001; McKenna *et al.*, 2005). The change in colour during aging is related to the oxidative processes and enzymatic reducing systems in controlling metmyoglobin levels in meat. Where the metmyoglobin reducing activity is thought to prolong the colour stability of muscles by reducing metmyoglobin to myoglobin as metmyoglobin is responsible for the brown discolouration that is unacceptable by consumers (Neethling *et al.*, 2016). The oxygenation of myoglobin to oxymyoglobin once the meat is exposed to oxygen (when removed from vacuum package) produces the bright cherry red colour that is the most desired by consumers (McKenna *et al.*, 2005; Lawrie & Ledward, 2006; Węglarz, 2010). Therefore vacuum packaged meat is darker than fresh meat due to lack of oxygen exposure that prevents oxidation of lipids and myoglobin, but turns bright red when bloomed (Coombs *et al.*, 2016). McKenna *et al.* (2005) categorised the LTL as a high colour stable muscle while BF was categorised as a low colour stable muscle when aged and subjected to retail display. Similarly, Neethling *et al.*, (2016) found that in blesbok (*Damaliscus pygargus phillipsi*) that the LTL was more colour stable than the BF. Volpelli *et al.*, (2003) reported that the dark colour associated with game meat that is attractive to consumers is characterised by an L^* value <40 , a high a^* and a low b^* value. This was

observed throughout the present study from day 2 until day 28. Therefore aging did not appear to have a negative influence on the colour of the meat with regards to consumer perspective.

There was no difference in the L^* (lightness) value between the different muscle types which was expected as McKenna *et al.*, (2005) noted that the L^* of meat colour appears to play a minimal role in the colour stability of muscles. Boakye & Mittal (1996) reported a gradual increase in the L^* of meat from day 0 to 16. This similar trend was observed in the present study with an increase from day 2 to day 14, followed by a decrease observed from day 20 to 28. This increase is attributed to vacuum packaging affecting the L^* value of meat due to an increased retention of oxygen in the outer layers of freshly cut meat since the oxygen-utilising enzymes in the deeper tissue progressively become inactivated with passing aging time (Boakye & Mittal, 1996). The increase in scattering of light is also influenced by the extent of protein denaturation which increases with aging, as well as an increase in purge loss increasing the scatter and reflected light (Colle *et al.*, 2015).

Differences in the a^* values as well as for the Chroma value, was observed between both the muscle types and aging period. This trend was expected because in Chapter 4 it was noted that the increase in a^* values had a greater contribution to an increase in Chroma values in blue wildebeest muscles. In the present study there was an increase in the a^* value with increase in storage time (Fig. 8.5). This could be attributed to the fact that there was no change in purge loss from day 9 of aging. An increase in purge loss is coupled to an increase in loss of water soluble protein myoglobin along with other water soluble nutrients (Colle *et al.*, 2015). Which also aids in explaining why the LTL has a lower a^* value than the BF, as it was associated with a higher purge loss than the BF. Since the CIE a^* value is generally positively correlated with the myoglobin concentration of meat and Chroma with the saturation/intensity of the colour, in the present study an increase with aging period could therefore have been associated with an increase in a more saturated red colour (Vestergaard *et al.*, 2000).

No difference in the b^* was observed between the different muscle types, however there was an increase with an increase in aging period. This indicates that the meat became a more yellow/brown colour with aging. This is caused by the oxidation of oxymyoglobin to metmyoglobin which exhibits as a brownish colour (Wiklund *et al.*, 2010). However the b^* value was lower than what has been recorded for beef after fourteen days of aging ($b^* = \sim 15.0$), making it less yellow than beef which is considered acceptable (Li *et al.*, 2013; Bureš *et al.*, 2015). This lower b^* value could be attributed to the higher pH values obtained in this study as lower pH causes lower oxygen consumption and therefore higher oxygen penetration and faster browning (Wiklund *et al.*, 2010). Similarly to the b^* reading, there was an increase in the hue-angle with increase in aging period which indicates an increase in redness over time.

The colour measurements recorded in the study at day 14 of aging ($L^* = 32.5 \pm 0.76$; $a^* = 15.1 \pm 0.72$; $b^* = 10.4 \pm 0.72$; Chroma = 18.3 ± 0.97 and hue-angle = 34.1 ± 0.94) compares

favourably with that reported for beef meat aged for 14 days in vacuum packaging ($L^* = 30.3$, $a^* = 18.8$, $b^* = 15.0$, Chroma = 24.1, hue – angle = 38.6) (Li *et al.*, 2013).

With the nutritional composition of meat products becoming more important to consumers it is necessary that information of meat products from all species be made available. The nutritional value and quality of meat is primarily defined by its basic chemical composition consisting of total moisture, protein, lipid and ash content, as these components account for nearly 100% of the weight of animal tissue (Ang *et al.*, 1984). The concentration of these chemical constituents generally differs between muscle types due to the difference in physiological function, activity and growth that is influenced by anatomical location. This causes differences in the composition of fibre types (red or white muscle fibres, the myofibrils and the spaces between filaments), IMF levels and connective tissue between muscles (Cassens & Cooper, 1971; Honikel, 1998; Lawrie & Ledward, 2006; Astruc, 2014; North & Hoffman, 2017). Therefore as expected there was a difference in the moisture ($p = 0.023$) and protein ($p = 0.007$) content, however, there was no difference in intramuscular fat (IMF) and ash content between the two muscle types. Regardless of these differences both muscles consisted of a nutritional composition that is associated with lean and healthy meat consisting of high protein (~21.5 – 23g per 100g) and low IMF (~1.5 - 1.8g per 100g). Studies have found that mammalian muscle is comprised of approximately 75% water (Huff-Lonergan & Lonergan, 2005). This study supported this statement with a moisture content that ranged from ~75 – 76% between the two muscle types. Even though there were statistically differences found in the proximate composition, it is questionable whether these differences are of biological value.

8.5. CONCLUSION

This study highlights that blue wildebeest meat tenderises rapidly during aging, with the ultimate shear force being reached as early as day nine post mortem. This is at a higher rate than observed in the aging of beef. However, there were differences in the tenderness of the two muscles tested with the LTL achieving better tenderness than BF throughout the aging period. Therefore, to achieve optimum meat quality in vacuum packed blue wildebeest LTL and BF muscles, it is recommended that the LTL be aged nine days and the BF 14 days at 4°C under vacuum storage. This period of post mortem aging was also associated with favourable cumulative purge loss, cooking loss and colour. Both muscles were also found to have a desired nutritional composition with high protein and low IMF contents. The findings of this study can also aid in the application of muscle specific information resulting in better product management that will result in more consistent and desirable eating experiences for the consumer. However since meat tenderness and other meat quality attributes are influenced by both intrinsic factors (e.g. age, sex, muscle type and marbling) and environmental factors (e.g. nutrition, ante mortem stress, slaughter process and chilling conditions and aging), it's important that this study be repeated to incorporate more of these factors so as to have more robust guidelines for game meat processors.

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CHAPTER 9

GENERAL CONCLUSIONS AND RECOMMENDATIONS

All indications are there that blue wildebeest that are farmed both extensively and semi-extensively in South Africa can provide meat of good-quality and healthy characteristics while contributing to food security, economic stability and maintaining biodiversity. This is because blue wildebeest that are harvested in South Africa are most often surplus animals and therefore meat products can be obtained as a means of population management. This study provided a reliable and science-based overview of the meat quality of this species, generating baseline data that can be beneficial to the meat industry in promoting (product labelling, consumer education and marketing) and processing the meat products obtained from this species that will encourage consumer-purchase initiatives.

The semi-extensive production system produced carcasses with better meat production potential by producing carcasses of heavier weights with heavier muscle weights and as a consequence also produced heavier weights of internal and external offal parts that can be utilized as a low-cost protein source due to animals being maintained on a high nutritional plane throughout the production year (Chapter 3). However despite this, production system had a minor influence on the physical meat quality, only influencing the drip loss percentage; higher losses being measured from samples from the semi-extensive system although the magnitude of these losses were such that they are unlikely to influence consumer perceptions (Chapter 4). Similarly production system did not have a major influence on the sensory profile or fatty acid profile of the meat but a desirable sensory profile was obtained from a consumer perspective (Chapter 6). This is possibly due to the selective eating habits of this species that cause them to eat similar vegetation regardless in which production system they are produced. In addition this study was done at the end of summer when vegetation is abundant, therefore future studies should be repeated during and at the end of winter when the natural vegetation is sparse, but the period when most hunting takes place. In contrast to physical quality parameters, production system had a greater (statistical) influence on the chemical composition with regards to proximate composition of the meat, differing for moisture, protein and ash content (Chapter 5). However despite these differences the meat produced was still high in protein and low in intramuscular fat, highlighting that the meat from this species is lean and healthy. Although statistical differences were regarded as significant, the actual differences were small and a study with a larger sample size should be used to confirm the trends found in this study regarding the proximate analysis.

In the meat industry it is well known that the age at slaughter plays a vital role in the quality of the meat produced. Therefore as expected, age influenced the drip loss, cooking loss, tenderness and lightness of the muscles, with the sub-adult animals producing meat samples of a more desirable characteristic in these physical parameters besides that of drip loss (Chapter 4). Therefore as expected the study done on only blue wildebeest of 28 months old age, produced meat of good-

quality (Chapter 7). Not only did they produce a carcass yield that was higher than conventional domestic species but also meat that was leaner and healthy (more protein and less IMF), which are currently of importance to consumers. However due to the small sample size, the age factor should be interpreted with caution. In order to get a more reliable result, a larger sample size with larger age differences should be used; to determine the optimum weight/age to slaughter. However it is always difficult to judge the age of wild ungulates when the period allowed to shoot is limited due to the inherent nature of wild animals therefore it is suggested that when age is a major experimental treatment that the study be performed in a more controlled environment where animals are kept in camps and their ages are known due to reliable record keeping, as was the case in this study.

The study highlighted differences in meat quality between the different muscles types, which were expected due to differences in function and anatomical locations. However knowing the meat quality differences between muscle types is important to ensure that the correct muscles are used for prime cuts while others are used in further processing. The forequarter muscles (IS and SS) were found to be desirable with regards to drip loss, cooking loss, tenderness and intense bright red colour in comparison to the hindquarter muscles (Chapter 4). For the chemical analyses it was found that the hindquarter muscles had a more nutritionally desirable composition, having a lower moisture content, higher protein content and lower IMF fat content than the forequarter muscles (Chapter 5). However all six muscles studied were within the range for the different physical parameters that are considered to be associated with good quality meat as well as being a lean and healthy alternative red meat source to conventional livestock red meat such as lamb and beef. With differences being so slight that it is doubtful whether differences would be noticeable by consumers. This study also highlighted that blue wildebeest meat tenderises rapidly during aging, with the ultimate shear force being reached for the LTL muscle at nine days of aging while the BF took slightly longer to 14 days which was associated with favourable cumulative purge loss, cooking loss and colour (Chapter 8). It should be emphasised though that these semi-extensive wildebeest were culled with minimal stress and that stress could play an important role in determining the optimal aging period for these two muscles.

So while the current study highlights that meat produced from blue wildebeest is lean, healthy, tender and tasteful, the current study had a number of limitations that underpins the requirement for further research because as eluded previously, carcass quality and meat quality is influenced by a number of factors. Firstly, with the game industry that is continuously developing, there is a continuous change in the way game species are being farmed, often to a more intensified production system to optimise production and allow for regular intervention. Therefore future research should include the investigation into the effects of intensive production systems, for example where animals only consume supplementary feed as well as where their movements are limited, on meat quality. In addition to this, the season of harvesting should also be considered as meat obtained from systems that rely on natural vegetation could adversely be affected due to

nutrient limitations and therefore mineral analysis and metabolism also warrants further research. Another interesting aspect would be to evaluate the chemical composition of the forage especially with regards to the fatty acid profile and then compare it to the meat fatty acid profile to see to what extent diet composition influences the chemical composition of the meat, as in this study it was postulated that differences in the fatty acids produced could have been influenced by the consumption of different types of grasses. This will also allow farmers to adjust diet formulations to obtain meat with the desired fatty acid profile and as a consequence sensory profile.

Another aspect that warrants further research is the quantification of the effect of sex particularly that of older, mature animals on the physical meat quality parameters, as this study was limited to only bulls. At the time of this study farmers were hesitant to get rid of their cows that could still be used for reproduction, however due to the surplus amount of animals currently being produced more cows that don't meet the breeding criteria will become available for meat production. The information about the meat quality of cows will then be essential for production and market entry.

Another aspect that warrants further research is at what age this species will provide the maximum meat (kg) per surface area (ha). Presently blue wildebeest cull bulls are harvested at 28 months as at this age the breeders are able to predict the breeding potential of a bull. To be able to determine the optimum age to slaughter these animals, a serial slaughter experiment will be needed wherein the change in meat yield, as well as all the other physical and chemical characteristics linked to the different muscles, need to be quantified. Included in such an experiment would be the reproduction cycle of this species as well so as to give a holistic value to kg meat produced per surface area.

With respect to the variation in muscles types being observed in this study, in-depth studies on the fibre types comprising these muscles should be done to better understand the variations between muscle types.

Since the safety of meat products are essential, this should be evaluated, especially in terms of microbial load as influenced by slaughter processes, chilling rates and chilling conditions to give a more robust guideline for game meat processors.

Lastly, there is also a need to identify the target market for game meat, both locally and internationally, in terms of product quality, in order to market products correctly that will encourage the growth of a successful game meat industry in South Africa.

Addendum I

Information on two blue wildebeest castrates compared to uncastrated blue wildebeest from an extensive and semi-extensive production system.

Results and Discussion:

Firstly it's important to note that the castrated animals did receive some degree of supplementary feed. There were no 40 month old extensive system animals to compare with and therefore 48 months old animals are used in this Addendum (Table 1).

The undressed carcass weights of the castrated animals were comparable to the animals of the extensive systems but lower than the animals from the semi-extensive system. However the castrates produced a much higher carcass weight than the extensive system attributed to the higher weight of the external offal of the extensive animals (Table 2), the animals from the semi-extensive system contributing the highest weight of the external offal parts. The differences in the total external offal parts are due to the weight of the heads (which includes the horns) (Table 2). It can clearly be seen that the weights of the heads from the castrates are significantly lower than the heads from the uncastrated animals. The difference in weight does not seem to be influenced by the length of the horns (Table 3), but rather the thickness of the horns. This conclusion was made by looking at the horn data collected at slaughter. The data showed no differences in the length of the horns but rather the thickness of the bases, especially when comparing the castrates to the uncastrated semi-extensive animals. The higher carcass weights generated by the animals of the semi-extensive animals explains the higher total weight of the selected muscles also produced by the animals of this system (Table 4), with little difference between the muscles weights of the castrates and the uncastrated animals from the extensive system. The dressing percentage of the castrates were more comparable to the semi-extensive system and higher than the extensive system (Table 1).

Table 1 LSMean carcass yields of blue wildebeest castrates (oxen) and two uncastrated bulls from different production systems.

Carcass yields		Oxen		Bulls	
		#1	#2	Extensive	Semi-extensive
Age		± 40 months	± 40 months	± 48 months	40 months
Undressed carcass	kg	195.5	185.4	190.5	221.3
carcass weight	kg	97.0	99.8	87.9	121.2
Dressing percentage	%	49.6	53.83	46.1	54.7

Table 2 LSMeans of offal contributions (kg and %) of blue wildebeest castrates (oxen) and two uncastrated bulls influenced by production system.

		Oxen		Bulls	
		#1	#2	Extensive	Semi-extensive
Undressed carcass	kg	195.5	185.4	190.5	221.3
Head	kg	12.9	12.9	14.1	16.8
	% ^{#1}	6.6	6.9	7.4	7.6
Legs	kg	4.6	4.1	3.9	4.4
	%	2.3	2.2	2	2
Skin	kg	14.5	13.5	16.7	18.4
	%	7.4	7.3	8.7	8.3
Total external offal	kg	32	30.5	34.7	39.7
	%	16.3	16.4	18.2	17.9
Heart	kg	1.3	1.1	1.2	1.5
	%	0.7	0.6	1.4	0.7
Lungs	kg	2.2	2.3	2.8	2.9
	%	1.1	1.2	1.1	1.3
Liver	kg	1.7	1.7	2.1	2.1
	%	0.9	0.9	0.3	1
Kidneys	kg	0.3	0.3	0.3	0.4
	%	0.1	0.1	0.3	0.2
Spleen	kg	0.6	0.4	0.5	0.6
	%	0.3	0.2	0.3	0.3
GIT	kg	55.3	45.8	46.3	42.7
	%	28.3	24.7	24.3	19.3
Total internal offal	kg	61.3	51.4	53.2	50.2
	%	31.4	27.8	27.9	22.7
Total	kg	93.3	81.9	87.4	89.9
	%	47.7	44.2	46.2	40.6

Variable % = contribution to the undressed carcass weight. Head= includes tongue and horns. GIT= Gastro-intestinal tract, includes stomach and intestines.

Table 3 LSMeans horn measurements (inches) for the blue wildebeest blue wildebeest castrates (oxen) and two uncastrated bulls influenced by production system.

Horn measurements	Oxen		Bulls	
	#1	#2	Extensive	Semi-extensive
Left base	11.8	10.3	11.8	14.2
Right base	11.0	10.8	12.2	13.6
Left horn length	20.9	19.9	20.1	22.3
Right horn length	20.3	19.9	19.7	21.9
Total length [#]	48.6	47.8	44.6	51.6

[#]Total length: Measurement started on the tip of the left horn along the horn thread, across the base, to the tip of the right horn.

Table 4 LSMeans weight (kg) and percentage contribution (%) to the cold carcass weight of six muscles (combined right and left sides) from blue wildebeest castrates (oxen) and two uncastrated bulls influenced by production system.

Muscle		Oxen		Bulls	
		#1	#2	Extensive	Semi-extensive
Carcass weight	kg	97.0	99.8	87.9	121.2
LTL	kg	4.8	4.9	5.0	5.9
	%	4.9	4.9	5.7	4.9
BF	kg	4.6	5.1	4.8	5.9
	%	4.7	5.1	5.5	4.9
SM	kg	3.5	3.7	3.8	4.6
	%	3.6	3.7	4.3	3.8
ST	kg	1.4	1.4	1.4	1.7
	%	1.4	1.4	1.6	1.4
IS	kg	1.4	1.5	1.3	1.5
	%	1.4	1.5	1.5	1.2
SS	kg	1.4	1.3	1.2	1.3
	%	1.4	1.3	1.4	1.1
Total	kg	17.1	17.9	17.5	20.9
	%	17.6	17.9	19.9	17.2

Abbreviations: LTL= *M. longissimus thoracis et lumborum*, BF= *M. biceps femoris*, SM= *M. semimembranosus*, ST= *M. semitendinosus*, IS= *M. infraspinatus*, SS= *M. supraspinatus*.

There was little difference in the ultimate muscle pH measured between the treatments with a slightly higher muscle pH being measured for castrate #2 attributed to the fact that this animal was very stressed during the culling process as the animal was chased for a few hours before a kill shot

could be taken. Due to the finding of the ultimate muscle pH being higher than normal (5.3-5.8) post-mortem for castrate #2, it was expected that this would influence the drip loss, cooking loss, tenderness and colour attributes of the meat from castrate #2. However this was not found and the results for these physical parameters were comparable between the different treatments with no differences seen in the parameters of castrate #2. However the LTL muscle of this animal measured a significantly lower a^* value than the other treatments, indicating a low myoglobin content, thus exhibiting a less saturated red colour than the other muscles and other LTL muscles from the other treatments. However, interestingly this muscle also measured a low b^* value which was unexpected as a low a^* value is usually associated with a high b^* due to the more yellow/brown colour of the muscle. Game meat is often associated with L^* value <40 , high a^* and low b^* values which was observed across all treatments.

The drip loss of the castrates ranged from 0.8 to 4.0% in the different muscle types. Expected due to variation in the fibre composition of the muscles due to differences in function and activity based on anatomical location of the different skeletal muscles. The high drip loss measured for the SM of castrate #1 could be due to higher surface area to volume ratio of this muscle that would lead to increased drip loss and not as a result of an increased pH. Otherwise it was comparable to the drip loss of the bulls that ranged from 0.9 to 1.8%. This low moisture loss is associated with good quality meat. There was no significant difference in the cooking loss between the castrates and the bulls, will castrates comparing favourably with the bulls. The low cooking loss is also associated with good quality meat as less moisture loss indicates juicier cooked meat that is preferred by consumers. Tenderness is the most important eating quality of meat. There was no clear difference between the tenderness of the castrates and the bulls. As expected there were differences in the different skeletal muscle types with most muscles falling in the tender range (< 42.8) with the exception of the SM muscle of the bulls. With the forequarter muscles being the most tender (lowest shear force values). Reasons for this are discussed in Chapter 4 of this study.

Therefore the main difference between castrated blue wildebeest (oxen) and uncastrated wildebeest (bulls) appears to be undressed weight due to differences in horn thickness and not length, with no difference in the meat quality parameters.

Table 5 LSMean of the physical meat quality parameters measured in six selected blue wildebeest muscles.

Parameter	Muscle type						
	Animal	LTL	BF	SM	ST	IS	SS
pH _U	Castrated (oxen) #1	5.6	5.8	5.8	5.7	5.7	5.7
	Castrated (oxen) #2	5.9	6.3	5.8	5.8	6.2	6.0
	Extensive bull	5.6	5.6	5.7	5.7	5.7	5.7
	Semi-extensive bull	5.7	5.6	5.7	5.8	5.9	5.9
Drip loss (%)	Castrated (oxen) #1	2.0	1.2	4.0	1.8	1.0	0.8
	Castrated (oxen) #2	1.2	1.0	1.2	1.4	1.0	0.9
	Extensive bull	1.8	0.9	1.7	1.3	1.2	1.3
	Semi-extensive bull	1.8	1.2	1.2	1.6	0.9	1.0
Cooking loss (%)	Castrated (oxen) #1	35.9	31.9	38.4	38.7	30.6	34.2
	Castrated (oxen) #2	34.9	34.4	39.1	39.3	31.9	45.6
	Extensive bull	35.9	39.9	41.6	42.0	29.8	38.9
	Semi-extensive bull	37.2	38.8	38.3	41.0	31.8	39.2

Table 6 *Continued.*

Parameter		Muscle type					
	Animal	LTL	BF	SM	ST	IS	SS
Shear force (Kg/1.27cm Φ)	Castrated (oxen) #1	25.8	33.2	39.3	32.8	26.6	23.9
	Castrated (oxen) #2	36.5	40.2	41.9	39.0	17.9	21.0
	Extensive bull	35.8	38.7	45.8	31.0	28.1	32.3
	Semi- extensive bull	40.6	43.1	44.8	35.3	26.3	25.6
Shear force (N)	Castrated (oxen) #1	3.3	4.3	5.1	4.2	3.4	3.1
	Castrated (oxen) #2	4.7	5.2	5.4	5.0	2.3	2.7
	Extensive bull	4.6	5.0	5.9	4.0	3.6	4.2
	Semi- extensive bull	5.2	5.6	5.8	4.6	3.4	3.3

Table 7 LSMeans for the meat quality colour parameters of six selected blue wildebeest muscles.

Parameter	Muscle type						
	Animal	LTL	BF	SM	ST	IS	SS
L*	Castrated (oxen) #1	35.5	39.7	35.1	39.6	33.0	34.7
	Castrated (oxen) #2	31.3	32.1	31.9	33.5	39.5	29.3
	Extensive bull	35.1	32.8	34.5	33.3	33.6	33.2
	Semi-extensive bull	31.5	29.5	32.5	29.1	30.7	31.1
a*	Castrated (oxen) #1	13.0	13.6	15.9	11.8	13.5	13.6
	Castrated (oxen) #2	9.0	12.3	13.6	13.4	14.4	13.5
	Extensive bull	11.6	10.4	11.8	10.4	15.4	16.4
	Semi-extensive bull	13.1	12.3	13.0	12.0	15.0	14.5
b*	Castrated (oxen) #1	9.7	10.5	11.9	8.8	7.9	9.3
	Castrated (oxen) #2	5.5	8.2	9.3	8.9	7.3	6.9
	Extensive bull	7.9	7.5	9.1	9.3	7.6	8.8
	Semi-extensive bull	7.6	8.5	9.9	9.8	8.5	7.9